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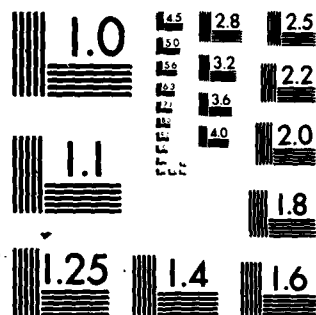
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**NAVAL AIR ENGINEERING CENTER**

REPORT NAEC-92-114

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**REDUCTION OF EXHAUST SMOKE FROM  
GAS-TURBINE ENGINES  
BY USING FUEL EMULSIONS**

Propulsion Support Equipment Division  
Support Equipment Engineering Department  
Naval Air Engineering Center  
Lakehurst, New Jersey 08733

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Final Report  
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# REDUCTION OF EXHAUST SMOKE FROM GAS-TURBINE ENGINES BY USING FUEL EMULSIONS

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 15 DAEC-92-114	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) REDUCTION OF EXHAUST SMOKE FROM GAS-TURBINE ENGINES BY USING FUEL EMULSIONS.	5. TYPE OF REPORT & PERIOD COVERED 9 Final Report	
6. AUTHOR(s) C. A. / Moses and C. W. / Coon	7. PERFORMING ORG. REPORT NUMBER 14 AFLRL No. 84	
8. AUTHOR(s) Revised by: P. A. / Altavilla (NAVAIRENGCEN)	9. CONTRACT OR GRANT NUMBER(s) 15 N68335-76-C-1136 w	
10. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Fuels & Lubricants Research Laboratory Southwest Research Institute, PO Box 28510 San Antonio, Texas 78284	11. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS A3400000/051B/7F57572401 WU 05	
12. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command AIR-340E Washington, DC 20361	13. REPORT DATE 21 October 1984	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Air Engineering Center Support Equipment Engineering Department (92) Lakehurst, New Jersey 08733	15. NUMBER OF PAGES 91	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		17. SECURITY CLASS. (of this Report) Unclassified
18. SUPPLEMENTARY NOTES Prepared by U.S. Army Fuels and Lubricants Research Laboratory in September 1976 for the Naval Air Engineering Center.		19. DECLASSIFICATION/DOWNGRADING SCHEDULE
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Combustor Testing      Turbine Engines      Exhaust Emissions Fuel-Water Emulsions      Turbine Engine Test Cells      Combustion Efficiency Emulsions      Exhaust Smoke      Smoke Reduction		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Low-internal-phase ratio emulsions of water-in-fuel have been investigated for their potential in reducing exhaust smoke from gas-turbine engines. The unique mechanism is the selective vaporization of the internal phase during the period of droplet heating.  Experiments were conducted in a combustor facility fabricated from T-63 engine hardware using a single-can combustor with a dual-orifice (over)		

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## 20. ABSTRACT

pressure atomizer.

Two series of tests were performed. The initial sequence employed air flow conditions that simulated full engine power (the smokiest condition). During the experiments, the fuel specifications, water concentration, surfactant concentration, and dispersion size were varied, and measurements of exhaust smoke, combustor temperature rise, flame radiation, and combustion efficiency based upon exhaust chemistry were obtained.

The initial series of experiments suggested that a 48 percent reduction in exhaust particulate concentration, based upon a correlation due to Champagne, was possible with an emulsion having a water-to-fuel ratio of 0.1.

The later series of tests was oriented toward optimization of the water concentration for smoke reduction and examination of the complete engine power spectrum. Continuous decreases in exhaust smoke were observed up to the highest concentration tested, a 0.5 water-to-fuel ratio. The maximum reduction in exhaust particulate concentration was 80 percent based upon the Champagne correlation. Emulsions composed of 15 and 30 percent water-in-fuel ratio were tested throughout the engine power range, and smoke reductions were observed at all power points. The greatest reductions were found at the highest power points where the smoke problem is the greatest.

Combustion efficiency was calculated from the exhaust chemistry and decreased with the addition of water. The reduction in efficiency was very small at full power but became quite significant at the lower power conditions. Comprehensive measurements of gaseous exhaust emissions were also reported.

Within the limits of combustor rig testing, the water-in-fuel emulsion concept was shown to have a potential for significant reductions in exhaust smoke at the high power conditions where smoke is the greatest problem; the reductions in combustor performance were minimal at these conditions. The concept shows less potential at the lower power levels of operation. Since increasing the water concentration continued to reduce smoke, in actual engine operation the concentration could be tailored to meet the required smoke level.

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## I. INTRODUCTION

Many present-day aircraft turbine engines produce exhaust with visible amounts of smoke. The objectionable conditions occur even though the smoke concentrations are very low and represent very small losses in combustion efficiency. Many recent studies have shown the directions necessary in combustor design for smoke abatement, and excellent results have been obtained. There remains, however, a problem in the testing of existing designs on stationary engine test stands where smoke production levels may be above environmental standards or desires.

Low-internal-phase-ratio emulsions of water-in-fuel have been investigated for their potential in reducing exhaust smoke from gas-turbine engines. The unique mechanism is the selective vaporization of the internal phase during the period of droplet heating; this vaporization and sudden expansion causes the fuel drop to break up into much smaller droplets. The potential for reducing soot formation in heterogeneous combustion is suggested by this increased atomization and dispersion of the fuel.

Experiments were conducted in a combustor facility fabricated from T-63 engine hardware using a single-can combustor with a dual-orifice pressure atomizer. Two series of tests were performed. The initial sequence employed air flow conditions that simulated full engine power (the smokiest condition). The second series employed air flow characteristics at reduced power conditions. During the experiments, the fuel specifications, water concentration, surfactant concentration, and dispersion size were varied. Moreover, measurements of exhaust smoke, combustor temperature rise, flame radiation, and combustion efficiency based upon exhaust chemistry were obtained.

## II. SUMMARY

A. During the experiments, it was observed that a concentration of 2% surfactant was sufficient to produce a stable emulsion that allowed significant smoke reduction; no benefit could be ascribed to the use of larger quantities. No effect of dispersion size on smoke reduction was directly observed, although the homogenizing equipment allowed only a small range of dispersion size to be investigated. Fuels which were characterized by high aromatic content and high boiling range were studied; the smoke reduction concept was found to be equally effective in both cases. Specifically, the initial series of experiments suggested that a 48% reduction in exhaust particulate concentration, based upon a correlation due to Champagne, was possible with an emulsion having a water-to-fuel ratio of 0.1. The flame radiation was reduced by 20%, and the reductions in combustor temperature rise and combustion efficiency were minimal. Since there was evidence of a continuing decrease in exhaust smoke with further increases in water concentration, an additional group of experiments was conducted.

B. The later series of tests were oriented toward optimization of the water concentration for smoke reduction and examination of the complete engine power spectrum. Continuous decreases in exhaust smoke were observed up to the highest concentration tested, a 0.5 water-to-fuel ratio. The maximum reduction in exhaust particulate concentration was 80% based upon the Champagne correlation. Emulsions composed of 15% and 30% water-in-fuel ratios were tested throughout the engine power range, and smoke reductions were observed at all power points. The greatest reductions were found at the highest power points where the smoke problem is the greatest.

C. Comprehensive measurements of gaseous exhaust emissions were also obtained.  $\text{NO}_x$  was reduced by increases in water concentration with the greatest reductions occurring at the higher power levels. CO and unburned hydrocarbons increased with water concentration; the increases were small at full power but became increasingly large at the lower power conditions. Combustion efficiency was calculated from the exhaust chemistry and decreased with the addition of water. The reduction in efficiency was very small at full power but became quite significant at the lower power conditions.

D. Within the limits of combustor rig testing, the water-in-fuel emulsion concept was shown to have a potential for significant reductions in exhaust smoke at the high power conditions where smoke is the greatest problem; the reductions in combustor performance were minimal at these conditions. The concept shows less potential at the lower power levels of operation, but smoke is not usually a problem during low power operation. Since increasing the water concentration continued to reduce smoke, in actual engine operation the concentration could be tailored to meet the required smoke level. Moreover, it is recommended that full-scale engine tests be conducted for the purpose of understanding the effects that water-fuel emulsions have on engine horsepower/operation and exhaust plume visibility.

### III. DISCUSSION AND THEORY

#### A. SMOKE PRODUCTION IN TURBINE ENGINE COMBUSTORS

1. The smoke produced by a gas turbine engine is an aerosol of soot or carbon particles resulting from the incomplete combustion of the fuel. Objectional conditions occur even though the particulate concentrations are very low, typically less than 0.005% by weight, and represent only very small losses in combustion efficiency (1).<sup>\*</sup> The major contribution is formed in the primary zone, but soot may be generated in any part of the combustor where mixing is inadequate and fuel-rich pockets exist. Essentially, the carbon loses to the more active and more available hydrogen in the competition for available oxygen. Most of this fine carbon or soot is consumed in the secondary and quench zones where there is an abundance of air; the remainder becomes exhaust smoke.

<sup>\*</sup>Numbers in parenthesis indicate items within the Bibliography.

2. The physical characteristics of the fuel spray have an important effect on the production of soot. Larger droplets have a longer lifetime, causing higher heat absorption and enhancing soot formation. Reduced spray penetration and cone angle serve to increase the fuel/air ratio in the region of the nozzle leading to an increase in soot production (3).

3. The hydrocarbon structure of the fuel is also known to have a significant effect on the production of soot. The higher molecular weight compounds are more prone to producing soot because of their higher carbon-hydrogen ratio; also they are less volatile and are often pyrolyzed before distilling out of the droplet. The existence of smaller droplets would allow the heavy ends to vaporize sooner so improved atomization may very well reduce this source. The aromatic compounds have a tendency to produce smoke about 30 times greater than that of the paraffins for the same boiling range (7) due to the relatively high stability of the carbon ring (16). This is an important consideration because of the latitude for aromatic composition in JP-5, 0-25% by volume.

#### B. SMOKE REDUCTION TECHNIQUES

1. Several techniques are generally used to reduce the smoke from new combustor designs: increased mixing and a leaner primary zone to reduce the production of soot and increased residence times in the secondary and quench zones to promote complete burning of the soot (2,3). Considerable success has also been obtained by using the so called "air blast" atomizer, which not only provides a smaller droplet size, but provides a source of oxygen immediately in the region of the nozzle orifice thus reducing the fuel-rich pocket found with pressure atomizers (3).

2. These solutions do not solve the problem associated with the testing of existing designs on stationary engine test stands where smoke production levels may exceed environmental standards. There are several fuel additives available which act to suppress smoke, such as Ethyl Corporation's Combustor Improver #2 and ferrocene. The former is a manganese additive and has potential toxicity problems as well as leading to the accumulation of manganese oxides on critical areas of the turbine; ferrocene also tends to create deposits, but they are sometimes acceptable (4, 5, 6).

#### C. "MICRO-EXPLOSION" PHENOMENA

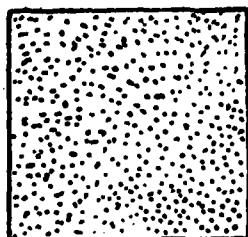
1. The combustion properties of drops of fuel emulsions were first investigated experimentally by Ivanov and Nefedov (14). Burning drops of water-in-oil emulsions and using high-speed cinematography, they showed that the more volatile water vaporized inside the drop as it was heated. The expansion of the water vapor violently tore the drop apart; this "micro-explosion" scattered very small droplets from the parent drop, increasing the total burning rate and reducing the carbon residue. Dryer (22) has

recently reproduced this experiment under a grant from the National Science Foundation.

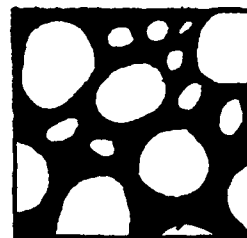
2. The potential for reducing soot formation from gas-turbine engines is suggested by this increase in atomization and dispersion of fuel. Dryer (22) reports several investigations of using fuel emulsions for the reduction of soot from furnaces and boilers; these all involved the use of fuel oils that are heavier than kerosene type jet fuels (JP-5). To the author's knowledge there has been no previous use of emulsions for the reduction of smoke from aircraft turbine engines.

#### D. CHARACTERISTICS OF EMULSIFIED FUELS

1. The type of emulsion used in this program is known as a low-internal-phase-ratio emulsion of water-in-oil. That is the "dispersed phase", water, is a relatively small fraction of the system and the "continuous phase", fuel, makes up the bulk of the system. The illustration below compares the structure of such an emulsion with its opposite, a high-internal-phase-ratio emulsion. Chemicals known as surfactants are usually required to stabilize emulsions. They are typically a type of molecule which is soluble in water on one end and soluble in oil on the other end. A proper balance of this Hydrophilic-Lipophilic property must be attained to achieve a stable emulsion; an HLB number is assigned to each surfactant to characterize it. The implications of this system are beyond the scope of this work. ICI American has published a description of the system (20). For reference, an HLB of 5.3 was found to be satisfactory. For low-internal-phase-ratio emulsions, the surfactant is usually ionic, so that the apparent charge can help prevent agglomeration and combustion which speeds separation.



Low-internal-phase-ratio  
water-in-oil



High-internal-phase-ratio  
oil-in-water

2. Low-internal-phase-ratio emulsions are desirable for the type of work discussed here for two reasons: the change in viscosity is not great and the characteristic size of the dispersed phase (water droplets) is smaller. The reason for the first is obvious; it was found that emulsifying 10% water in the JP-5 raised the viscosity from 1.6 cS to 2.0 cS. (High-internal-phase-ratio emulsions usually have very high viscosities and non-Newtonian flow properties.) The second is inherent to the "micro-explosion" phenomena: the size of the dispersed phase must be much smaller than the mean diameter of the fuel spray so that spray drops will contain the emulsion. Emulsions of 10% water in JP-5, stabilized with a surfactant, were examined under a microscope, and the dispersed water droplets were found to be in the range of 1/2 to 2 microns. Since the SMD of the fuel spray was about 85 microns, the spray remains an emulsion. Figure 1 shows two photo micrographs of emulsions created under different conditions. A circle is superimposed to give an indication of the interior of an 85 micron fuel drop. If the dispersion size becomes the same order as a spray drop, the free surfaces of the emulsion will interfere with normal droplet formation process, and quite probably, the drops will not be emulsions, but either pure fuel or water.

#### IV. EQUIPMENT AND PROCEDURES

A. EXPERIMENTAL EQUIPMENT. With the exception of the fuel emulsification system, all of the experimental equipment used in this program was existing equipment already being used in turbine-fuels research at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL).

##### 1. FUEL EMULSIFICATION SYSTEM

a. The system used to make the emulsions was a Model 100 Laboratory Homogenizer manufactured by the Gaulin Corporation. It was chosen over other methods, such as ultrasonics, because it provided a capability for varying the dispersion size of the emulsion. Basically, the unit is a high-pressure, positive displacement pump which discharges a crudely mixed medium through a special homogenizing valve (see Figure 1). The mixture is accelerated through the orifice to strike the impact ring at velocities up to 300 m/sec (950 ft/sec); this action shatters the mixture into a dispersion of very small droplets. This dispersion size can be varied by adjusting the orifice size and pressure drop; examples of the resulting emulsions are illustrated in Figure 2.

b. The homogenizer unit was integrated into the fuel system as an in-line emulsification system, thereby reducing the emulsion stability requirements. The system is shown schematically in Figure 3. The fuel and water are crudely mixed in the "mixing tee" upstream of the homogenizer. The first bypass system recycles excess flow because the pump operates at a constant flow rate of 4.1 l/min (65 gph) whereas the combustor only requires 1.9 l/min (30 gph) at the operating conditions used. The second bypass is

used to establish the correct flow rates of the two liquids before introducing the fuel into the combustor. The accumulator is necessary to dampen the pulsations in line pressure caused by the piston-compressor action of the homogenizer.

2. EMULSION ANALYSIS. The emulsions were analyzed for dispersion size by using a microscope with 430x magnification. A micrometer slide with 0.1 mm divisions was used to calibrate the scale on the eyepiece. Each division on the eyepiece was equivalent to about .003 mm so droplets of .001 mm could be measured to an accuracy of .0005 mm.

3. COMBUSTOR RIG. The combustor rig used for this study is based on engine hardware from the Allison T-63 engine used in the Navy's TH-57A helicopter. The burner is a single-can type with a dual orifice pressure atomizer centered in the dome as shown in Figure 4. At the exit of the burner can there is a centerbody which diverts the flow into an annulus where the nozzles and turbine blades are normally located. Gas-sampling probes, pressure probes, and thermocouples were arranged circumferentially in one plane of this annulus at various radial positions, as shown in Figure 5. Figure 6 shows the combustor rig as installed and instrumented in the AFLRL combustor lab. Table 1 presents the air flow and fuel flow conditions that were established to correspond with various power points following the guidelines of the manufacturer.

4. FLAME RADIATION MEASUREMENT. Total flame radiation was measured with Model R-2065 Asymptotic Radiometer manufactured by Hy-Cal Engineering. Figure 7 illustrates the installation of this unit. The window is sapphire to permit response to IR radiation out to around 5 microns; this is necessary to see the CO<sub>2</sub> radiation (19). The important feature is that the window is flush with the combustor liner wall and has a 150° viewing angle. Thus, it sees essentially the entire flame zone and measures the total radiation heat load to the wall at that point. This wide viewing angle is important in programs where the temperature patterns may shift due to changes in air-fuel mixing.

5. DATA ACQUISITION SYSTEM. The heart of the data acquisition system is a Hewlett-Packard 9820 programmable calculator; this is coupled to a scanner and digital voltmeter to automatically acquire data and process it. Operating conditions are then printed out for monitoring on a thermal line printer with an update about every ten seconds. The flow rates of the combustor air and fuel were measured with turbine flowmeters. All pressures were sensed with strain gauge pressure transducers activated by regulated power supplies. Chromel-alumel thermocouples, referenced to a 150°F regulated oven, were used for temperature measurement.

6. EXHAUST ANALYSIS INSTRUMENTATION. Exhaust emissions were measured on-line using the instruments listed on the following page.

<u>Sample</u>	<u>Instrument</u>	<u>Sensitivity</u>
Carbon Monoxide	Beckman Model 315B NDIR	50 ppm to 16%
Carbon Dioxide	Beckman Model 315B NDIR	300 ppm to 16%
Unburned Hydrocarbons	Beckman Model 402 FID Hydrocarbon Analyzer	0.5 ppm to 10% (CH <sub>4</sub> )
Nitric Oxide	Thermo-Electron 10A Chemiluminescence Analyzer	3 ppm to 10,000 ppm
Total Oxides of Nitrogen	Thermo-Electron 10A Chemiluminescence Analyzer with NO <sub>x</sub> Convertor	3 ppm to 10,000 ppm
Oxygen	Beckman Fieldlab Oxygen Analyzer	0.1 ppm to 100%

The exhaust sample was brought to the instruments through a 350°F heated teflon line and then appropriately distributed.

7. SMOKE ANALYSIS SYSTEM. The system used for measuring exhaust smoke level was designed according to the requirements of SAE-ARP1179. Briefly, a sample of the exhaust is passed through a strip of filter paper. Particulates from the exhaust are trapped on the surface, leaving a spot ranging in "grayness" from white to black, depending on the sample size and particulate content of the exhaust. The spot is then evaluated with a reflectometer. Refer to VB3 for detailed calculation.

8. FUELS. Three fuels of the JP-5 type were used in this program. Two of the three test fuels were specially blended at a local refinery to accentuate the two "smoke sources" within the fuel as previously discussed, i.e., one fuel had a high boiling range and a low aromatic content while the other had a high aromatic content but a lower boiling range. The third test fuel was simply a production-run JP-5 from Ashland Refinery. Table 2 compares the properties of these fuels to the JP-5 specification.

B. PROCEDURES. The objective of this program was to determine the potential of reducing the exhaust smoke from a gas-turbine combustion chamber by emulsifying the fuel with water. The program was separated into seven major phases:

Phase 1 -- Formation and Characterization of Emulsions

Phase 2 -- Combustor Testing to Evaluate Potential for Smoke Reduction

Phase 3 -- Sensitivity of Concept to Pertinent Fuel Properties

Phase 4 -- Support Data on Best Candidate Emulsion

Phase 5 -- Effect of Best Emulsified Fuel on Combustion Throughout the Power Spectrum

Phase 6 -- Evaluation of the Effects of Particulate Emission Rates on Exhaust Plume Visibility

Phase 7 -- Estimate of Effects During Full-Scale Engine Tests

1. In Phase 1, the formation and characterization of stable emulsions of water-in-fuel were investigated. Possible candidate emulsion systems were identified, and an in-line system was developed to create emulsions of variable concentration and quality.

2. During the second phase, these emulsions were tested in a combustor rig operated at the smokiest condition to determine their potential in reducing exhaust smoke and to assess the effects of the fuel-modification on combustor performance, i.e., flame radiation, exhaust emissions, combustion efficiency, and temperature rise. The fuel used in the second phase was a "production run" JP-5.

3. In Phase 3, two specially blended JP-5 fuels were used to determine if the concept was sensitive to boiling-range end-point or aromatic content. These variables constitute two major fuel-related sources of soot formation in combustors.

4. Phase 4 was devoted to further combustor tests using additional water concentrations. Both 100% and 25% power levels were examined in an attempt to identify the emulsion characteristics that were optimum for smoke reduction.

5. During Phase 5, the combustor was operated over the entire power spectrum using the base fuel and fuel emulsions considered appropriate for full-scale engine testing.

6. The effort during Phase 6 was devoted to estimation of probable plume visibility on the basis of measured particulate emission rates.

7. All of the information acquired during the program was utilized during Phase 7. In this activity, estimates were made of the probable effect of fuel-water emulsions on plume visibility and particulate emission rates during full-scale engine tests.

The work associated with Phases 1-3 was performed during 1975, and the results have been reported previously on an interim basis. This report encompasses the entire effort, Phases 1-7, and includes all information previously submitted.

## V. ANALYSIS

A. PRESENTATION OF DATA. There are two types of data presentation: the test reports of the individual combustor experiments and the smoke data. Since the smoke data is derived from analysis and curve fitting of smoke spots on filter paper, it is not included in the individual test report which is immediate output from the calculator at the completion of each test.

1. The test reports are presented as Figures 8 through 62 and give summaries of the combustor operating conditions, a survey of the exhaust thermocouple measurements, the exhaust chemistry and the combustion efficiencies. Average values and standard deviations of the air and fuel flow parameters are compared with the desired engine parameters as given in Table 1.

2. The least-squares curve fits of the smoke spot readings for all the experiments are presented in Figures 63 through 77. Many of the experiments are combined on the various figures to help illustrate the effects on smoke reduction.

### B. COMBUSTION PARAMETERS

1. Combustion Efficiency. Combustion efficiencies are calculated from the exhaust gas analysis according to a relationship developed by Hardin (11):

$$\eta_b = \left[ 1 - \frac{A \cdot f(\text{UBH}) - 121,745 \cdot f(\text{CO}) - 38,880 \cdot f(\text{NO}) - 14,654 \cdot f(\text{NO}_2)}{A \cdot [f(\text{CO}_2) + f(\text{CO}) + f(\text{UBH})]} \right] \cdot 100\%$$

where  $f(i)$  is the concentration of "i", in the exhaust and A is a constant based on the heat of combustion and hydrogen/carbon ratio of the fuel.

2. Flow Rate. The pressure and flow rate cannot always be attained exactly; in such cases the air flow loading factor is the critical scaling parameter which is matched along with the air/fuel ratio and the inlet temperature. The flow parameter is defined as:

$$\text{FF} \equiv \frac{W \sqrt{T}}{P}$$

where W = air flow rate

T = temperature

P = air pressure

It is a measure of the mach number of the inlet air flow and hence the residence time in the combustor. This is a standard scaling method used by engine manufacturers (10).

3. Smoke Level. The sample particulate matter, as aforementioned in IVA7, is evaluated using a reflectometer. The calculation which assigns a smoke number (SN) to the sample is as follows:

$$SN = 100 \left( 1 - \frac{R_s}{R_w} \right)$$

where  $R_s$  and  $R_w$  are the diffuse reflectance of the sample spot and the clean filter paper. Exhaust samples are taken over a range of sample sizes around  $W/A = 0.023$  pound of sample per square inch of filter area. The resulting smoke numbers are plotted against  $\log (W/A)$ . These are least-squares fitted with a straight line; the interpolated value of SN at  $W/A = 0.023$  is the reported smoke number for the engine operation condition. Champagne (9) gives a complete description of the procedure and relates the results to particulate concentration and exhaust plume visibility. Troth et al (10) provide a numerical relationship for that correlation:

$$d_s = a_1 \exp (a_2 SN) [1 - \exp (-a_3 SN)] + a_4 \exp [-a_5 (SN - a_6)^2]$$

where  $d_s$  = true smoke density,  $\text{mg}/\text{m}^3$

SN = EPA Smoke Number

$$a_1 = 0.8$$

$$a_2 = 0.057565$$

$$a_3 = 0.1335$$

$$a_4 = 0.0942$$

$$a_5 = 0.005$$

$$a_6 = 27.5$$

## VI. DISCUSSION OF EXPERIMENTAL RESULTS

### A. COMBUSTOR OPERATING CONDITIONS

1. Examination of the test reports shows that the air and fuel flow parameters were all quite stable during the tests which normally take about 20 minutes to complete because of the lengthy smoke measurements. (Unfortunately, due to an error in the programming, the "air flow loading factor" was printed out as "0.00" in the first seven experiments. Calculated values are written in.) The differences in fuel flow rate and air/fuel ratio account for the water and surfactant added to the fuel. The actual fuel flow rate was kept the same for all experiments conducted at similar power points. Another deviation in the printed output from the calculator was encountered during the second series of experiments. The method of reporting hydrocarbon emissions was inconsistent with the computer program; corrections have been made on the experiment test reports.

2. Except for the noted variances, a comparison of the operating conditions shows very little variation among the experiments. They are therefore felt to be a valid set of experiments upon which to base conclusions about the use of fuel emulsions to reduce exhaust smoke.

### B. CHARACTERIZATION OF EMULSIONS

1. Four emulsion characteristics were found to be important in this program:

- a. surfactant type,
- b. surfactant concentration,
- c. water concentration, and
- d. dispersion size.

2. The first has already been discussed briefly. An HLB kit was purchased and used to find the desirable value for a water-in-JP5 emulsion. A surfactant with an HLB of 5.3 (90% SPAN 80\*/10% TWEEN 80\*) was used for the combustion experiments.

3. The surfactant concentration was also found to have an effect on the stability. ("Stable" here means the emulsion exhibits no separation to the unaided eye; agglomeration and coescence on a microscopic scale always occur to some extent.) The amount of surfactant necessary depended on the concentration of water. Emulsions of 10% water-in-JP5 could be stabilized for up to 12 hours with 2% of the above surfactant, whereas emulsions of 20% and 30% water showed separation in about 15 minutes. Only concentrations of 5% and 10% water were used in the early combustion experiments. Surfactant levels were maintained at the 2% value during the later tests, which included water-to-fuel ratios up to 50%. The in-line homogenizer unit allowed stable emulsions to be maintained during the performance of the tests.

\* Trademarks of ICI America, Inc.

4. It should be noted that the percentage definitions are related to the fuel flow above; the total flow of liquid to the combustor was not used as the reference. Thus, the term "20% emulsion" implies a mixture of one part of water to five parts of fuel on a volume basis. Surfactant concentrations are also based upon a measured volume of fuel, and the surfactant was mixed with the fuel prior to initiation of the combustion tests.

5. The dispersion size could be varied by changing the pressure drop across the homogenizer valve as previously discussed. The two photomicrographs of Figure 2 show the dispersions for the pressure drops of 2600 and 200 psi--the two extremes used in the combustion experiments. The scale is 3 microns per division for both pictures. The high-pressure case indicates dispersions of around 1 to 2 microns, whereas the dispersion in the other case is 5 to 10 microns with a few larger sizes apparent.

C. COMBUSTION EXPERIMENTS. In addition to the individual test reports for each experiment, the salient features of the experimental program are summarized in Tables 3 and 4. The following discussion treats several pertinent aspects of the use of emulsified fuels in turbine combustors.

#### 1. Exhaust Smoke

a. Without exception, the addition of water to the fuel in the form of an emulsion resulted in a reduction in exhaust smoke. The results from the early series of experiments, summarized in Figure 78, suggest that significant reduction in smoke can be achieved through the addition of modest quantities of water. Furthermore, the trend of these results implies that larger quantities of water yield further smoke reduction. The more recent experiments confirm this tendency; results are shown for water/fuel ratios up to 50% in Figures 79 and 80. Throughout this series of tests, smoke was further reduced for each increase in water concentration. Although the shape of the curve implies that a limiting value exists, higher concentrations were not attempted since the physical properties of emulsions begin to change at concentrations not too far above this (18).

b. Since the test results indicate that exhaust smoke decreases monotonically as the water concentration increases, there is no clearly defined optimum value for the water content of the emulsion. In practice, the selection of an appropriate blend would be governed by the magnitude of the smoke emission problem and by practical considerations associated with the engine fuel supply system. A body of data was acquired which describes the degree of smoke reduction available over the entire engine operating range. Water-in-fuel ratios of 0.15 and 0.30 were utilized; the results are described in Figures 81 and 82. The full power point corresponds to maximum smoke, and it is particularly significant to note that the greatest smoke reductions were achieved at the high power points. The lower power points are characterized by smaller smoke reductions, but the smoke levels are also low under low power conditions. In terms of smoke number, at the full power point, reduction by a factor of approximately 2 is possible at the 0.15 water-in-fuel ratio, while the addition of 0.30 water-in-fuel ratio allows smoke reduction by a factor of about 3.

c. During the early series of experiments, an attempt was made to produce emulsions having different dispersion sizes by varying the homogenizer pressure drop. Estimated dispersion sizes ranged from 1 to 10 microns; these values are much smaller than the SMD of the spray. When these mixtures were tested, no effect of dispersion size was observed. However, it is probable that the relatively unstable emulsions produced with low surfactant concentrations are characterized by larger dispersion sizes. The results shown in Figure 78 indicate that the smoke reduction is affected by surfactant concentrations below a level of about 2%. Thus, it may be inferred that there is some effect of dispersion size, but the effect is quite small if the surfactant concentration and initial dispersion are sufficient to create a stable emulsion.

2. Combustor Temperature Rise. There is no apparent effect on temperature rise; this could be expected considering the very small amount of water actually added. With an overall fuel/air ratio of 0.0198, an addition of 12.1% wt (10% vol) of water based on the fuel is only an addition of 0.24% wt of the total flow. Assuming the specific heat of water vapor is twice that of air, the resultant decrease in temperature rise should be about 0.5%. If the temperature rise is typically about 630°C (1170°F), the effect is only 3°C (6°F)!

3. Combustion Efficiency. Combustion efficiencies were calculated from the combustor exhaust chemistry, and the results are shown in Figures 83 and 84. At full power, the efficiency is reduced by less than 1% at water/fuel ratios of 0.50. However, the effect of water addition is more noticeable for part load operation. As shown in Figure 84, the combustion efficiency for a 0.30 water-in-fuel emulsion at the 10% power point is about 4% lower than the value associated with the base fuel.

4. Flame Radiation. Burning emulsions of 10% water consistently resulted in about a 20% reduction in flame radiation. This is consistent with the idea that less soot is being produced in the primary zone.

5. Exhaust Chemistry. Measurements of exhaust concentrations were obtained for unburned hydrocarbons, carbon monoxide, and oxides of nitrogen. The results are summarized, with respect to water fuel ratio and power point, in Figures 85 through 90. In general, it may be observed that an increase in the water concentration corresponds to an increase in emission of unburned hydrocarbon and carbon monoxide and a decrease in emission of oxides of nitrogen. The changes are significant; the emission of oxides of nitrogen can be halved by the addition of 40% water, but the cost of this reduction is an increase of the same magnitude in emission of hydrocarbons. The observed trend corresponds to the effect of a cooler flame zone. The cooler flame may be due either to a water quench effect or to changes in the mixing of air and fuel. The increase dispersion of the fuel as a result of micro-explosions would reduce the level of high temperature diffusion-zone combustion and promote cooler premixed combustion.

D. SENSITIVITY TO FUEL PROPERTIES. The reductions in smoke brought about by emulsifying the fuel were equally effective with high aromatic fuels and fuels with high end points as evidenced by experiments 16 through 19. Therefore, no problems are foreseen in the application of this concept due to variations in fuel properties.

## VII. EVALUATION OF CONCEPT AND APPLICATION OF RESULTS

Two correlations, attributed to Champagne (9) and Kelly (21), have been located to establish the correspondence between smoke number and plume visibility. Champagne provides an indication of the size of a visible plume in terms of smoke number (or smoke concentration). The correlation due to Kelly is a summary of data obtained from Navy jet engine test facilities. Both of the correlations are presented in Figure 91. Obviously, reductions in smoke number coincide with reductions in plume visibility, but the actual relationship depends upon the engine and installation. This program has shown that fuel emulsions can be used to reduce exhaust smoke with negligible effects on combustor performance. Therefore, it is concluded that there would be reductions in plume visibility if such a fuel is used in a full-scale engine, but the extent of the reduction cannot be predicted.

The concept of water-in-fuel emulsions reducing exhaust smoke from gas turbine engines appears to have its greatest application at full power conditions where the smoke problem is most severe. The greatest reductions in smoke were obtained under full power conditions, and the effect of water addition on combustion efficiency and combustor temperature rise was smallest at these points. Because the smoke levels were found to be monotonically decreasing with increased water concentration, it appears that the addition of water can be tailored to meet the level of smoke being produced.

The adaption of the technique to full-scale engine testing could be accomplished in two ways: if the fuel control system is flexible enough to accommodate the required increase in fuel flow, the easiest method would be to emulsify the fuel upstream of the high-pressure pump; the other possibility is to emulsify the fuel between the fuel control and the nozzle ring by temporarily replacing a section of the high-pressure line with an emulsification system similar to the one used in this program. The choice may depend on the individual engine.

## VIII. RECOMMENDATION

Two important performance items cannot be quantified on a combustor test facility; these factors are (1) the effects on engine horsepower and operation, and (2) the effects on exhaust plume visibility. It is therefore recommended that full-scale engine tests be conducted in order to define these features of water-fuel emulsion time.

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TABLE 1 - T-63 COMBUSTOR RIG OPERATING CONDITIONS

Mode	% Power	BIP kpa (psia)	BIT °C (°F)	$\omega_a$ kg/s (lb/s)	$\omega_f$ kg/m (lb/m)	F/A	FF	BOT °C (°F)
Ground Idle	10	252 (36.6)	149 (300)	0.699 (1.54)	0.46 (1.01)	.0109	1.158	561 (1042)
--	25	311 (45.1)	178 (353)	0.0821 (1.81)	0.59 (1.31)	.0121	1.145	648 (1199)
Descent	40	363 (52.6)	204 (400)	0.948 (2.09)	1.74 (1.64)	.0131	1.163	699 (1290)
Cruise	55	417 (60.5)	221 (430)	1.03 (2.27)	0.89 (1.97)	.0145	1.147	759 (1399)
Climb/Hover	75	461 (66.9)	244 (472)	1.12 (2.46)	1.11 (2.45)	.0166	1.123	848 (1559)
Takeoff	100	525 (76.2)	273 (524)	1.21 (2.66)	1.43 (3.16)	.0198	1.094	971 (1780)

Nomenclature

BIP: Burner inlet air pressure  
 BIT: Burner inlet air temperature  
 $\omega_a$ : Air flow rate  
 $\omega_f$ : Fuel flow rate  
 F/A: Fuel/air ratio  
 FF:  $\omega_f / \text{BIT/BIP}$   
 BOT: Typical burner outlet temperature

TABLE 2 - FUEL PROPERTIES

	FUEL*			
	<u>JPS-HBR</u>	<u>JPS-HA</u>	<u>JPS-P</u>	<u>JPS-Spec.</u>
<u>Composition</u>				
Saturate, normal	18.8	15.8	5.8	--
Saturate, iso- and cyclo-	67.8	59.9	80.9	--
Aromatic	13.4	24.3	13.3	<25%
<u>Volatility</u>				
<u>Distillation</u>				
Initial (°F)	390	366	356	--
10%	406	380	384	400 max
20%	412	384	394	--
50%	430	394	422	--
90%	488	436	476	--
95%	510	466	490	--
Final	536	496	504	550 max
Flash Point, °F	162	145	142	140 min
Gravity, API (60°F)	42.7	42.1	42.4	36 to 48
Specific Gravity (75°F)	.81	.81	.81	.788 to .845
<u>Fluidity</u>				
Freeze Point, °F	-22	-52.6	-54	-51 max
Viscosity (100°F)	1.78	1.37	1.59	--
<u>Combustion</u>				
Aniline Gravity Product	6700	5759	6285	4500 min
Heat of Combustion, BTU/lb	19,827	19,702	19,757	18,300 min

\*JPS-HA was the high aromatic JPS,  
 JPS-HBR was the high boiling range JPS, and  
 JPS-P was the production JPS.

TABLE 3 - SUMMARY OF COMBUSTOR EXPERIMENTS  
PROGRAM PHASES 1-3

All Runs at Full Power Conditions

Exper. No.	Date	Base Fuel	Water Conc. %Vol	Surfactant Conc. %Vol	$\Delta p^3$ psi	NO ppm	NO <sub>x</sub> ppm	THC ppm	CO %	Smoke No.	Particulate Conc. mg/m <sup>3</sup>	Combustion Efficiency %	Combustor Temp. Rise °C (°F)	Combustor Flame Radiation %W/m <sup>2</sup>
1	6/13/75	JPS-P	0	0	--	57.5	61.5	2.9	0.033	24.4	3.22	99.6195	661 (1221)	--
2	6/13/75	JPS-P	10	2	2600	49.0	53.0	7.4	0.036	16.9	1.95	99.5618	638 (1181)	--
3	6/13/75	JPS-P	10	2	1600	45.0	55.5	6.8	0.040	17.0	1.96	99.5254	637 (1179)	--
4	6/13/75	JPS-P	10	2	200	43.5	54.5	6.0	0.040	17.3	2.01	99.5311	632 (1170)	--
5	6/18/75	JPS-P	0	0	--	52.5	58.0	3.6	0.032	25.5	3.45	99.6121	623 (1153)	19.9
6	6/18/75	JPS-P	10	1	2600	44.5	51.5	5.3	0.038	18.5	2.19	99.5484	637 (1178)	15.9
7	6/18/75	JPS-P	10	1/2	2600	48.0	56.2	4.8	0.033	21.5	2.68	99.6096	645 (1193)	16.7
8	6/19/75	JPS-P	0	0	--	52.6	58.5	3.4	0.033	27.1	3.80	99.6000	618 (1144)	--
9	6/23/75	JPS-P	0	0	--	58.0	63.5	2.2	0.032	27.6	3.91	99.6344	647 (1197)	19.1
10	6/23/75	JPS-P	0	2	--	51.5	58.3	3.8	0.035	26.6	3.69	99.5690	635 (1175)	19.1
11	6/25/75	JPS-P	0	0	--	55.4	61.5	3.4	0.032	27.2	3.82	99.6142	634 (1174)	18.6
12	6/25/75	JPS-P	10	3	2600	45.0	52.5	5.7	0.040	18.9	2.25	99.5225	633 (1172)	14.2
13	6/25/75	JPS-P	5	2	2600	51.7	59.5	3.4	0.033	21.4	2.66	99.6193	646 (1195)	15.4
14	6/25/75	JPS-P	5	1	2600	50.5	57.5	3.6	0.035	23.0	2.95	99.5872	633 (1171)	14.7
15	6/25/75	JPS-P	5	1/2	2600	52.5	58.5	3.6	0.035	24.0	3.14	99.5838	628 (1163)	14.5
16	6/27/75	JPS-HA	0	0	--	60.5	66.5	2.5	0.033	33.6	5.55	99.6089	635 (1175)	17.9
17	6/27/75	JPS-HA	10	2	2600	48.5	54.5	5.3	0.039	23.8	3.11	99.5286	623 (1170)	14.1
18	6/27/75	JPS-HBR	0	0	--	52.5	60.0	3.2	0.036	25.0	3.35	99.5741	621 (1150)	14.6
19	6/27/75	JPS-HBR	10	2	2600	45.0	51.6	6.4	0.041	15.4	1.74	99.5011	622 (1152)	11.9

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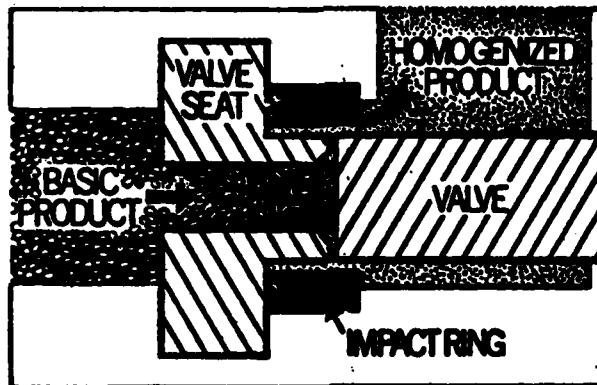
1. JPS-P was the production JPS,  
JPS-HA was the high aromatic JPS, and  
JPS-HBR was the high boiling range JPS.

2. Calculated from Champagne's correlation to Smoke Number (Ref. 9).

3. Pressure drop across "Memogenisor valve" which affects dispersion size.

TABLE 4 - SUMMARY OF COMBUSTOR EXPERIMENTS  
 PROGRAM PHASES 4-7  
 Fuel For All Runs Includes Surfactant 2% By Volume  
 Homogenizer Valve Pressure Drop = 2600 PSI For All Emulsions

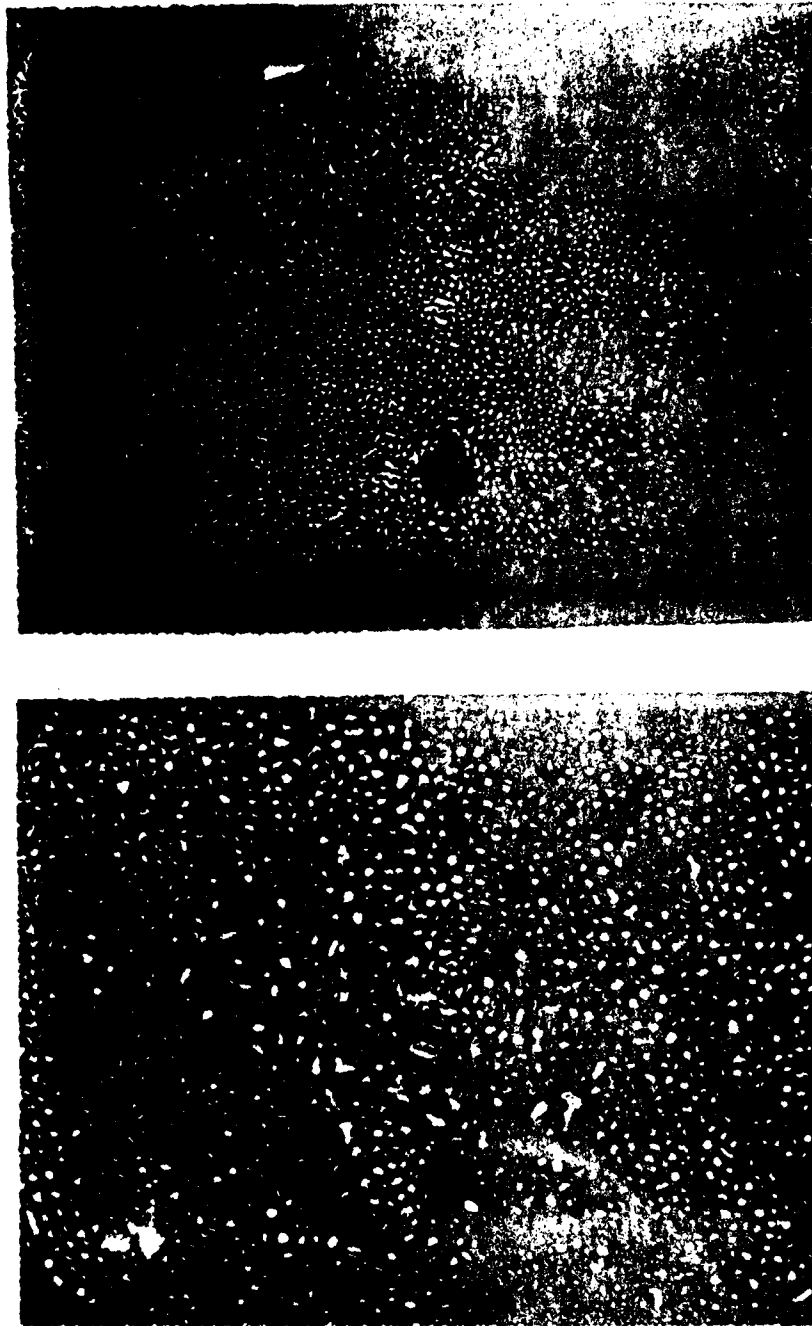
Expt. No.	Date	Base Fuel	Water Conc. Vol %	Power Point %	NO PPM	NOx PPM	THC PPM (Propane)	CO %	Smoke No.	Particulate Conc. mg/m <sup>3</sup>	Combustion Efficiency %	Combustor Temp Rise °C (°F)
20	6/17/76	JPS-P	0	100	55.5	62.0	9.4	.036	29.7	4.43	99.5442	-----
21	6/17/76	JPS-P	5	100	46.5	55.5	6.1	.043	19.0	2.26	99.4818	643 (1189)
22	6/17/76	JPS-P	10	100	43.5	51.5	8.3	.045	21.5	2.68	99.4568	648 (1199)
23	6/17/76	JPS-P	15	100	44.0	52.3	5.4	.044	17.6	2.05	99.4976	657 (1215)
24	6/17/76	JPS-P	20	100	33.0	41.5	11.4	.052	14.7	1.64	99.3529	642 (1188)
25	6/17/76	JPS-P	25	100	29.5	38.3	14.7	.058	12.2	1.33	99.2685	637 (1178)
26	6/18/76	JPS-P	0	100	50.3	60.5	3.6	.039	29.4	4.35	99.5348	642 (1188)
27	6/18/76	JPS-P	5	100	46.3	55.0	6.3	.046	22.3	2.82	99.4528	648 (1198)
28	6/18/76	JPS-P	30	100	26.3	34.4	20.8	.063	12.9	1.41	99.1670	639 (1193)
29	6/18/76	JPS-P	40	100	20.5	29.5	30.7	.073	10.2	1.09	99.0028	625 (1156)
30	6/18/76	JPS-P	0	25	11.7	19.3	140.0	.096	14.6	1.63	96.7323	416 (781)
31	6/18/76	JPS-P	10	25	12.3	17.0	253.3	.122	8.6	0.91	95.0419	413 (776)
32	6/18/76	JPS-P	20	25	10.7	13.7	327.7	.135	5.6	0.59	94.0669	406 (762)
33	6/18/76	JPS-P	30	25	8.8	11.3	393.7	.142	4.8	0.51	93.0364	386 (727)
34	6/18/76	JPS-P	40	25	8.0	9.7	468.0	.152	3.3	0.35	92.1171	392 (738)
35	6/21/76	JPS-P	0	100	56.0	61.7	3.6	.036	28.5	4.13	99.5685	646 (1194)
36	6/21/76	JPS-P	40	100	25.0	31.0	25.5	.070	9.3	0.99	99.0824	622 (1152)
37	6/21/76	JPS-P	50	100	20.5	26.4	38.9	.080	8.2	0.87	98.8921	617 (1142)
38	6/21/76	JPS-HBR	0	100	49.8	55.5	4.3	.040	26.6	3.687	99.5018	624 (1155)
39	6/21/76	JPS-HBR	15	100	35.8	41.5	14.2	.056	13.2	1.451	99.2684	626 (1158)
40	6/21/76	JPS-HBR	30	100	26.0	33.0	28.6	.069	9.3	0.990	99.0190	606 (1123)
41	6/21/76	JPS-HBR	0	75	29.4	39.0	34.7	.067	24.3	3.203	98.8143	543 (1009)
42	6/21/76	JPS-HBR	15	75	23.0	29.3	89.0	.099	12.3	1.339	97.9108	514 (958)
43	6/22/76	JPS-HBR	30	75	20.5	25.0	101.3	.104	7.6	0.803	97.8667	534 (994)
44	6/22/76	JPS-HBR	0	55	22.5	30.3	75.7	.084	19.0	2.265	98.0293	453 (848)
45	6/22/76	JPS-HBR	15	55	13.5	23.8	158.0	.109	9.9	1.057	96.8638	430 (805)
46	6/22/76	JPS-HBR	30	55	15.3	18.8	194.3	.121	5.9	0.622	96.4240	437 (818)
47	6/28/76	JPS-HBR	0	40	15.4	21.2	112.3	.091	13.3	1.463	97.3384	449 (840)
48	6/28/76	JPS-HBR	15	40	12.8	16.8	200.0	.120	5.2	0.548	96.0315	440 (824)
49	6/28/76	JPS-HBR	30	40	10.2	12.7	270.3	.136	3.3	0.350	95.0206	442 (792)
50	6/28/76	JPS-HBR	0	25	11.0	15.3	163.7	.114	7.3	0.771	96.1639	414 (778)
51	6/28/76	JPS-HBR	15	25	9.3	12.3	286.7	.135	3.4	0.360	94.4594	404 (759)
52	6/28/76	JPS-HBR	30	25	7.5	9.5	374.7	.148	2.2	0.235	93.0219	385 (725)
53	6/28/76	JPS-HBR	0	10	6.8	9.5	249.7	.124	6.8	0.717	94.0701	347 (657)
54	6/28/76	JPS-HBR	15	10	5.3	8.2	437.7	.150	2.9	0.308	91.1468	349 (660)
55	6/28/76	JPS-HBR	30	10	4.4	6.6	511.3	.160	1.8	0.193	89.8932	327 (620)



Close-up of a Gaulin homogenizing valve section. Product enters the valve area at high pressure. The pressure forces open the pre-loaded adjustable valve and the product passes through the aperture where an instantaneous pressure drop of less than an atmosphere occurs, causing shearing action and cavitation bubbles. The product then strikes the impact ring at a velocity of about 57,000 ft/min, further shattering the particles by impact and implosion of the bubbles. The homogenized product is discharged at a pressure sufficient for movement to the next processing stage.

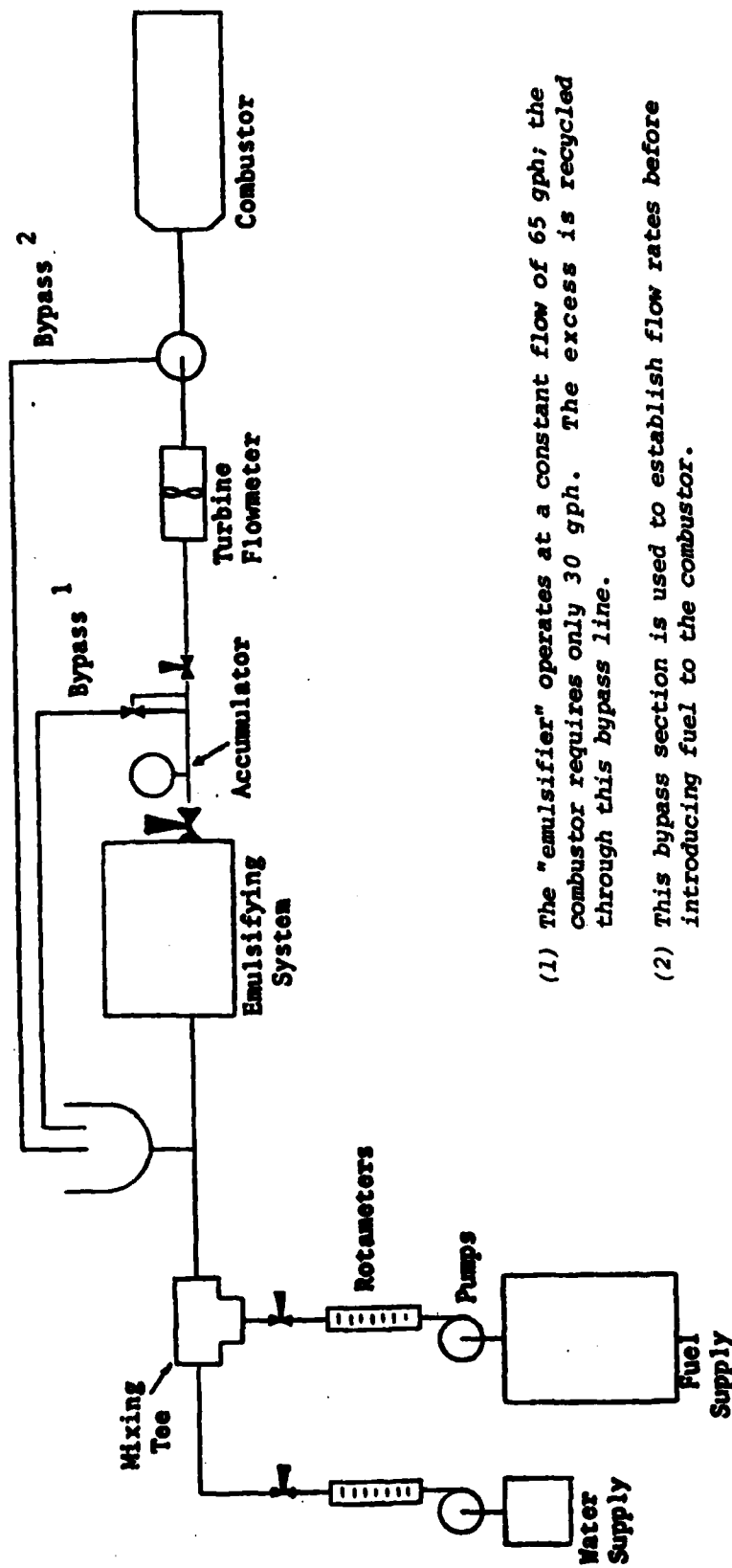
(from Bibliog 4)

Figure 1 - Mechanism of Emulsion Formation



Photomicrographs of emulsions formed with two different homogenizing pressures. (1) Upper:  $\Delta P = 2600$  psi., (2) lower: 200 psi. Scale: 3 microns/division. Circle is scaled to an 85-micron diameter to illustrate a spray drop of emulsion.

Figure 2 - Photomicrographs of Emulsions Showing Variation in Dispersion Size



- (1) The "emulsifier" operates at a constant flow of 65 gph; the combustor requires only 30 gph. The excess is recycled through this bypass line.
- (2) This bypass section is used to establish flow rates before introducing fuel to the combustor.

Figure 3 - Flow Diagram of Experimental In-Line Fuel Emulsification System



Figure 4 - T-63 Combustor Liner



Figure 5 - Exhaust Instrumentation Section

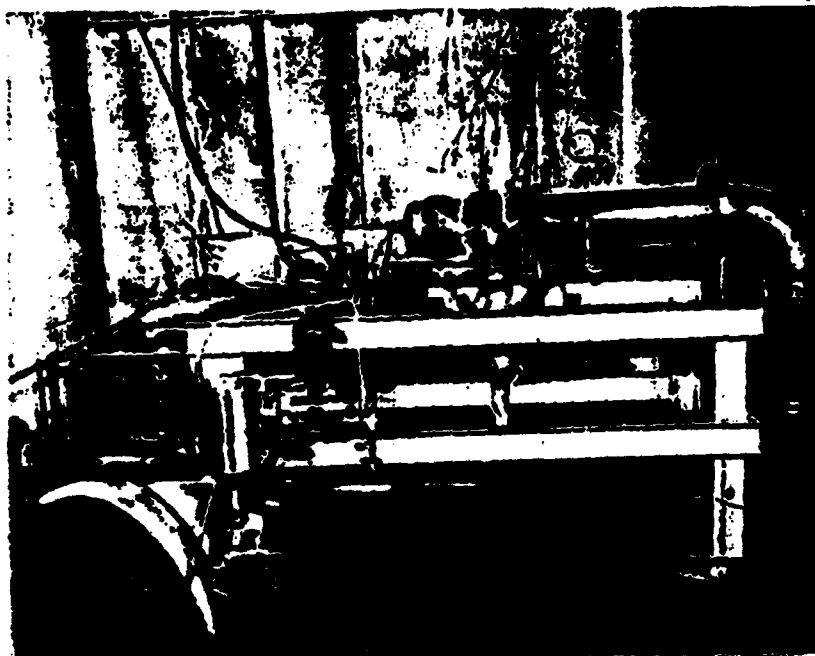


Figure 6  
T-63 Combustor  
Rig Installation

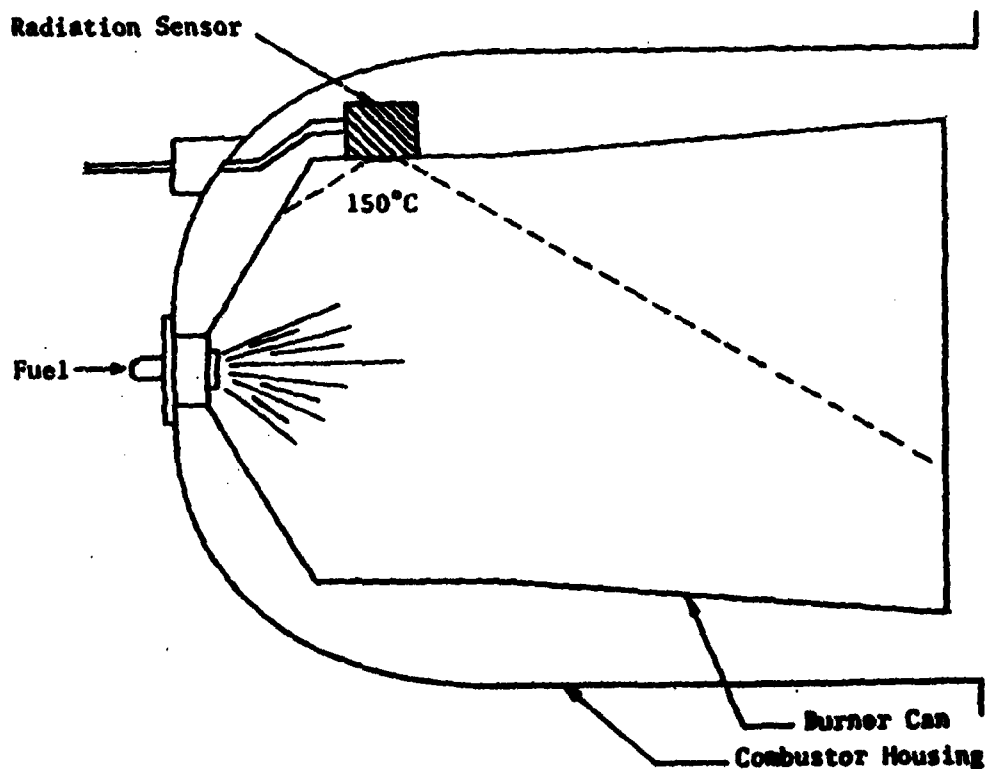


Figure 7 - Flame Radiation Measurement

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---  
U.S. ARMY AIR ENGINEERING CENTER

DATE: 6/13/73  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P  
TIME: 10:16  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 69.94  
INLET AIR TEMPERATURE, DEG F 522.74  
AIR FLOW RATE, LBS/SEC 2.512  
FUEL FLOW RATE, LBS/MIN 2.990  
FUEL/AIR RATIO .0194  
AIR FLOW LOADING FACTOR 9.0000  
DESIRED 76.20  
AVERAGE STD. DEV. .41  
524.00  
2.660  
3.160  
.0190  
1.0000  
LAST SCAN  
522.38  
2.916  
2.987  
.0197  
0.0000

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 83.5 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1741.0 DEG F  
BOT HOT SPOT: TCR 8 = 1824 DEG F  
BOT PATTERN FACTOR = .0658  
OUTER ANNULUS 1 1797  
4 1920  
7 1769  
10 1776  
13 1796  
16 1824  
19 1747  
22 1719  
25 1682  
28 1765  
STD DEV  
19  
13  
11  
32  
12  
14  
11  
11  
26  
22  
7  
27

\* EXHAUST CHEMISTRY \*

CO.. .033 % CO2..4.50 % UHM.. 2.9 PPM (PROPANE)  
H2O.. 57.5 PPM NOX.. 4.0 PPM (NOX-10)  
SNOKE NUMBER: 2.7

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: .99.6195 %  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .020028  
PERMITS:

Figure 8 - Test Report of Experiment No. 1

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---  
U.S. ARMY AIR ENGINEERING CENTER

DATE: 6/13/73  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P  
TIME: 11:15  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.25  
INLET AIR TEMPERATURE, DEG F 522.70  
AIR FLOW RATE, LBS/SEC 2.485  
FUEL FLOW RATE, LBS/MIN 3.355  
FUEL/AIR RATIO .02251  
AIR FLOW LOADING FACTOR 9.0000  
DESIRED 76.20  
AVERAGE STD. DEV. .32  
524.00  
2.660  
3.160  
.0190  
1.0000  
LAST SCAN  
522.38  
2.916  
2.987  
.0197  
0.0000

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 112.0 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1785.3 DEG F  
BOT HOT SPOT: TCR 5 = 1856 DEG F  
BOT PATTERN FACTOR = .1276  
OUTER ANNULUS 1 1779  
4 1843  
7 1710  
10 1483  
13 1782  
16 1856  
19 1851  
22 1530  
25 1749  
28 1736  
STD DEV  
16  
15  
1  
32  
16  
17  
19  
14  
14  
126  
33  
12  
46

\* EXHAUST CHEMISTRY \*

CO.. .036 % CO2..4.50 % UHM.. 7.4 PPM (PROPANE)  
H2O.. 49.8 PPM NOX.. 4.0 PPM (NOX-10)  
SNOKE NUMBER:

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: .99.9610 %  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .021652  
PERMITS:

10% H<sub>2</sub>O, 3000 PSI Emulsion procedure

Figure 9 - Test Report of Experiment No. 2

# U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U. S. ARMY AIR ENGINEERING CENTER

DATE: 6/13/72  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 10% WATER  
TIME: 11:31  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.89  
INLET AIR TEMPERATURE, DEG F 523.52  
AIR FLOW RATE, LBS/SEC 2.474  
FUEL FLOW RATE, LBS/MIN 3.327  
FUEL/AIR RATIO .02241  
AIR FLOW LOADING FACTOR 0.0000  
DESIRED 76.20  
1.32  
0.012  
2.668  
3.168  
0.01986  
1.0940  
LAST SCAN 71.50  
524.11  
2.473  
3.317  
0.02236  
0.0000

FUEL PRESSURE= 2400  
FUEL TEMPERATURE= 123.3 DEG F

## BURNER OUTLET TEMPERATURE SURVEY

BOT AVG=1293.4 DEG F  
BOT HOT SPOT: TCM 5 = 1837 DEG F  
BOT PATTERN FACTOR = .1137

OUTER ANNULUS  
TCR AVERAGE STD DEV  
1 1798 28  
4 1829 18  
7 0 1  
10 1765 14  
13 1499 26  
16 1778 28  
19 1837 22  
22 1827 19  
25 1563 16  
28 1742 13  
31 1725 14  
34 0 135  
37 0 170  
40 0 15  
43 1474 53

CENTER ANNULUS

INNER ANNULUS

## EXHAUST CHEMISTRY

CO... 940 % CO2... 4.50 % O2... 14.6 % UBN... 6.8 PPM PROPANE  
NO... 42.3 PPM NOX... 55.5 PPM NO2... 13.5 PPM (NOX+NO)  
SHAKE NUMBER: 16.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5254 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021554  
REMARKS: 3000 PSI Heavy-duty process

Figure 10 - Test Report of Experiment No. 3

# U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U. S. ARMY AIR ENGINEERING CENTER

DATE: 6/13/72  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 10% WATER  
TIME: 11:55  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 72.28  
INLET AIR TEMPERATURE, DEG F 522.79  
AIR FLOW RATE, LBS/SEC 2.467  
FUEL FLOW RATE, LBS/MIN 3.284  
FUEL/AIR RATIO .02219  
AIR FLOW LOADING FACTOR 0.0000  
DESIRED 76.20  
1.22  
0.013  
2.668  
3.168  
0.01986  
1.0940  
LAST SCAN 72.88  
523.68  
2.443  
3.293  
0.02247  
0.0000

FUEL PRESSURE= 2400  
FUEL TEMPERATURE= 97.4 DEG F

## BURNER OUTLET TEMPERATURE SURVEY

BOT AVG=1893.4 DEG F  
BOT HOT SPOT: TCM 5 = 1808 DEG F  
BOT PATTERN FACTOR = .0976

OUTER ANNULUS  
TCR AVERAGE STD DEV  
1 1719 14  
4 1796 13  
7 0 1  
10 1664 12  
13 1515 10  
16 1768 14  
19 1808 16  
22 1787 15  
25 1555 15  
28 1720 12  
31 1671 14  
34 0 118  
37 0 198  
40 0 12  
43 1633 42

CENTER ANNULUS

INNER ANNULUS

## EXHAUST CHEMISTRY

CO... 940 % CO2... 4.50 % O2... 14.8 % UBN... 6.8 PPM PROPANE  
NO... 43.5 PPM NOX... 54.5 PPM NO2... 11.0 PPM (NOX+NO)  
SHAKE NUMBER: 17.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.9311 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021412  
REMARKS: 600 PSI Heavy-duty process

Figure 11 - Test Report of Experiment No. 4

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-19-75 TIME: 9:40  
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JPS-P

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.26  
INLET AIR TEMPERATURE, DEG F 525.33  
AIR FLOW RATE, LBS/SEC 2.509  
FUEL FLOW RATE, LBS/MIN 2.975  
FUEL/AIR RATIO 0.1975  
AIR FLOW LOADING FACTOR 0.0023  
DESIRED LAST SCAN  
76.20  
524.00  
2.660  
3.160  
0.027  
0.0023  
0.0000  
7.249

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 97.4 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1633.4 DEG F  
BOT NOT SPOT: TCR 8 = 1827 DEG F  
BOT PATTERN FACTOR = .1541

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1648	36	
4	1773	12	
7	1759	15	
10	1511	64	
13	1359	80	
16	1744	36	
19	1827	13	
22	1827	13	
25	1572	13	
28	1736	10	
31	1563	11	
34	1639	22	
37	0	117	
40	0	73	
43	1543	72	

\* EXHAUST CHEMISTRY \*

CO.. .032 % CO2..4.33 % O2..13.2 % UHM.. 3.6 PPM (PROPANE)  
NO.. 52.5 PPM NOX.. 58.0 PPM NO2.. 3.5 PPM (NOX-NO)  
SMOKE NUMBER: 25.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6121 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020335  
REMARKS:

Figure 12 - Test Report of Experiment No. 5

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-19-75 TIME: 10:19  
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JPS-P EMULSIFIED WITH 10% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.38  
INLET AIR TEMPERATURE, DEG F 525.83  
AIR FLOW RATE, LBS/SEC 2.495  
FUEL FLOW RATE, LBS/MIN 3.273  
FUEL/AIR RATIO 0.02167  
AIR FLOW LOADING FACTOR 0.0006  
DESIRED LAST SCAN  
76.20  
524.00  
2.660  
3.160  
0.027  
0.0023  
0.0000  
7.249

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 122.4 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1704.5 DEG F  
BOT NOT SPOT: TCR 5 = 1838 DEG F  
BOT PATTERN FACTOR = .1134

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1759	36	
4	1785	11	
7	1767	17	
10	1489	40	
13	0	50	
16	1741	36	
19	1838	13	
22	0	15	
25	1583	13	
28	1743	14	
31	1635	13	
34	0	103	
37	0	159	
40	0	189	
43	1583	120	

\* EXHAUST CHEMISTRY \*

CO.. .038 % CO2..4.42 % O2..13.1 % UHM.. 5.3 PPM (PROPANE)  
NO.. 44.5 PPM NOX.. 51.5 PPM NO2.. 7.3 PPM (NOX-NO)  
SMOKE NUMBER: 18.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5464 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020351  
REMARKS: 1% fuel

Figure 13 - Test Report of Experiment No. 6

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY,  
TURBINE COMBUSTOR FACILITY  
STOP OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/19/75  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 10% WATER  
TIME: 11:22  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 72.77 DESIRED 76.20 LAST SCAN 71.60  
INLET AIR TEMPERATURE, DEG F 525.60 .95 524.00 523.89  
AIR FLOW RATE, LBS/SEC 2.458 .017 2.660 2.497  
FUEL FLOW RATE, LBS/MIN 3.289 .031 3.330 3.335  
FUEL/AIR RATIO .02231 .00026 .02200 .02226  
AIR FLOW LOADING FACTOR -0.00000 0.00000 1.0940 0.0000  
FUEL PRESSURE= 0  
FUEL TEMPERATURE=123.7 DEG F

\* BURIER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1719.1 DEG F  
BOT HOT SPOT: TCR 5 = 1860 DEG F  
BOT PATTERN FACTOR = .1131

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1781	20	
4	1808	19	
7	1782	18	
10	1573	29	
13	0	13	
16	1762	20	
19	1868	21	
22	1840	29	
25	1591	18	
28	1766	16	
31	1685	16	
34	0	11	
37	0	35	
40	0	32	
43	1541	60	

\* EXHAUST CHEMISTRY \*

CO<sub>2</sub>: .932 % CO<sub>2</sub>: 4.50 % O<sub>2</sub>: 14.7 % UHM: 4.8 PPM (PROPANE)  
NO<sub>x</sub>: 48.8 PPM NO<sub>x</sub>: 56.2 PPM NO<sub>2</sub>: 8.2 PPM (NOX-NO)  
SO<sub>2</sub>: 0.5% Sulfur

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: .99.6095 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021495  
REMARKS:

Figure 14 - Test Report of Experiment No. 7

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY,  
TURBINE COMBUSTOR FACILITY  
STOP OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/19/75  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P  
TIME: 11:11  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.22 DESIRED 76.20 LAST SCAN 71.10  
INLET AIR TEMPERATURE, DEG F 525.10 .95 524.00 524.54  
AIR FLOW RATE, LBS/SEC 2.495 .014 2.660 2.477  
FUEL FLOW RATE, LBS/MIN 3.295 .026 3.160 2.984  
FUEL/AIR RATIO .01873 .00028 .01900 .02008  
AIR FLOW LOADING FACTOR 1.0996 .0004 1.0940 1.0930  
FUEL PRESSURE= 0  
FUEL TEMPERATURE= 87.9 DEG F

\* BURIER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1645.2 DEG F  
BOT HOT SPOT: TCR 6 = 1796 DEG F  
BOT PATTERN FACTOR = .1330

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1700	13	
4	1703	17	
7	1597	29	
10	1528	13	
13	1418	60	
16	1729	13	
19	1772	12	
22	1796	13	
25	1581	11	
28	1711	11	
31	0	12	
34	0	120	
37	0	30	
40	0	80	
43	1573	93	

\* EXHAUST CHEMISTRY \*

CO<sub>2</sub>: .933 % CO<sub>2</sub>: 4.30 % O<sub>2</sub>: 16.1 % UHM: 3.4 PPM (PROPANE)  
NO<sub>x</sub>: 52.8 PPM NO<sub>x</sub>: 58.5 PPM NO<sub>2</sub>: 5.9 PPM (NOX-NO)  
SO<sub>2</sub>: 0.5% Sulfur

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: .99.6860 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .019526  
REMARKS:

Figure 15 - Test Report of Experiment No. 8

S. ARMY FUEL & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY  
U.S. NAVY AIR ENGINEERING CENTER  
U.S. ARMY AIR ENGINEERING CENTER

DATE: 6-23-76  
COMBUSTION SYSTEM: T-63  
TEST FUEL: JP5-P  
TIME: 11:06  
POWER POINT: 100%  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 72.60  
INLET AIR TEMPERATURE, DEG F 525.72  
AIR FLOW RATE, LBS/SEC 2.329  
FUEL FLOW RATE, LBS/MIN 3.168  
FUEL/AIR RATIO 0.0192  
AIR FLOW LOADING FACTOR 1.1828  
DESIRED LAST SCAN  
76.20  
524.00  
2.660  
3.168  
0.0190  
1.0940

FUEL PRESSURE= 0  
FUEL TEMPERATURE=125.8 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1701.0 DEG F  
BOT HOT SPOT: TCB 8 = 1784 DEG F  
BOT PATTERN FACTOR = .0705  
OUTER ANNULUS  
1 1714  
4 173  
7 1622  
10 1623  
13 1731  
16 1758  
19 1784  
22 1585  
25 1720  
28 196  
31 205  
34 1721  
37 33  
CENTER ANNULUS  
1 1714  
4 173  
7 1622  
10 1623  
13 1731  
16 1758  
19 1784  
22 1585  
25 1720  
28 196  
31 205  
34 1721  
37 33  
INNER ANNULUS  
1 1714  
4 173  
7 1622  
10 1623  
13 1731  
16 1758  
19 1784  
22 1585  
25 1720  
28 196  
31 205  
34 1721  
37 33

\* EXHAUST CHEMISTRY \*

CO... 035 % CO2... 4.23 % O2... 15.0 % UHM... 3.8 PPM (PROPANE)  
NO... 51.5 PPM NOX... 58.3 PPM NO2... 6.8 PPM (NOX-NO)  
SMOKE NUMBER: 2.6

CONDUCTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5690 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020387  
REMARKS: Fuel + 2% Surfactant but no water  
Delta H = 3000 psi

Figure 17 - Test Report of Experiment No. 10

S. ARMY FUEL & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY  
U.S. NAVY AIR ENGINEERING CENTER  
U.S. ARMY AIR ENGINEERING CENTER

DATE: 6-23-76  
COMBUSTION SYSTEM: T-63  
TEST FUEL: JP5-P  
TIME: 10:58  
POWER POINT: 100%  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 72.60  
INLET AIR TEMPERATURE, DEG F 526.70  
AIR FLOW RATE, LBS/SEC 2.328  
FUEL FLOW RATE, LBS/MIN 3.168  
FUEL/AIR RATIO 0.0190  
AIR FLOW LOADING FACTOR 1.0963  
DESIRED LAST SCAN  
76.20  
526.70  
2.660  
3.168  
0.0190  
1.0940

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 85.7 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1634.2 DEG F  
BOT HOT SPOT: TCB 8 = 1828 DEG F  
BOT PATTERN FACTOR = .1543  
OUTER ANNULUS  
1 1757  
4 1547  
7 144  
10 1633  
13 1773  
16 1792  
19 1828  
22 1624  
25 1769  
28 196  
31 196  
34 1788  
37 13  
CENTER ANNULUS  
1 1757  
4 1547  
7 144  
10 1633  
13 1773  
16 1792  
19 1828  
22 1624  
25 1769  
28 196  
31 196  
34 1788  
37 13  
INNER ANNULUS  
1 1757  
4 1547  
7 144  
10 1633  
13 1773  
16 1792  
19 1828  
22 1624  
25 1769  
28 196  
31 196  
34 1788  
37 13

\* EXHAUST CHEMISTRY \*

CO... 032 % CO2... 4.50 % O2... 14.7 % UHM... 2.2 PPM (PROPANE)  
NO... 58.0 PPM NOX... 63.5 PPM NO2... 5.5 PPM (NOX-NO)  
SMOKE NUMBER: 2.7

CONDUCTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6344 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021477  
REMARKS:

Figure 16 - Test Report of Experiment No. 9

# U. S. NAVY FUELS & LUBRICANTS RESEARCH LABORATORY

TESTING OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-25-78 TIME: 9:18  
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JPS-P

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

	AVERAGE	STD. DEV.	DESIRABLE	LAST SCAN
INLET AIR PRESSURE, PSIA	72.66	.20	76.20	72.40
INLET AIR TEMPERATURE, DEG F	524.20	1.88	524.03	524.11
AIR FLOW RATE, LBS/SEC	2.524	.013	2.650	2.530
FUEL FLOW RATE, LBS/MIN	2.999	.025	3.160	2.981
FUEL/AIR RATIO	.01981	.00020	.01960	.01964
AIR FLOW LOADING FACTOR	1.0596	.0063	1.0940	1.0942

FUEL PRESSURE = 0  
FUEL TEMPERATURE = 86.1 DEG F

## \* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1662.1 DEG F  
BOT HOT SPOT: TCR 8 = 1815 DEG F  
BOT PATTERN FACTOR = .1343

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1778	12	12
4	1512	60	6
7	0	6	6
10	1616	16	21
13	1648	21	12
16	1778	430	11
19	0	11	11
22	1815	11	11
25	1591	11	11
28	1746	10	10
31	1593	30	30
34	0	14	14
37	1687	35	35
40	1453	22	22
43	1757		

## \* EXHAUST CHEMISTRY \*

CO... .932 % CO2...4.35 % O2...13.2 % UH... 3.4 PPM (PROPANE)  
NO... 53.4 PPM NOX... 61.5 PPM NO2... 6.1 PPM (NOX-NO)  
SULFUR NUMBER: 2.7.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6142 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020502

Figure 18 - Test Report of Experiment No. 11

# U. S. NAVY FUELS & LUBRICANTS RESEARCH LABORATORY

TESTING OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-25-78 TIME: 9:37  
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JPS-P EMULSIFIED WITH 10% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

	AVERAGE	STD. DEV.	DESIRABLE	LAST SCAN
INLET AIR PRESSURE, PSIA	72.55	.28	76.20	72.50
INLET AIR TEMPERATURE, DEG F	524.85	1.10	524.00	525.62
AIR FLOW RATE, LBS/SEC	2.516	.012	2.660	2.508
FUEL FLOW RATE, LBS/MIN	3.294	.034	3.330	3.377
FUEL/AIR RATIO	.02103	.00027	.02200	.02244
AIR FLOW LOADING FACTOR	1.0879	.0075	1.0940	1.0862

FUEL PRESSURE = 0  
FUEL TEMPERATURE = 119.9 DEG F

## \* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1642.6 DEG F  
BOT HOT SPOT: TCR 8 = 1820 DEG F  
BOT PATTERN FACTOR = .1590

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1783	14	14
4	1500	68	3
7	0	21	21
10	1615	14	14
13	1601	14	14
16	1764	14	14
19	0	195	14
22	1820	14	14
25	1596	14	14
28	1741	12	12
31	0	11	11
34	0	178	34
37	1610	73	73
40	1282	18	18
43	1755		

## \* EXHAUST CHEMISTRY \*

CO... .940 % CO2...4.40 % O2...14.4 % UH... 5.7 PPM (PROPANE)  
NO... 45.0 PPM NOX... 52.5 PPM NO2... 7.5 PPM (NOX-NO)  
SULFUR NUMBER: 18.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5225 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021490

REMARKS: 3000 P.S.I. 3% avg.

Figure 19 - Test Report of Experiment No. 12

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY

100% OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*  
U.S. ARMY AIR ENGINEERING CENTER

DATE: 6/25/75 TIME: 10:43  
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JPS-P EMULSIFIED WITH 5% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 72.50  
INLET AIR TEMPERATURE, DEG F 524.33  
AIR FLOW RATE, LBS/SEC 2.507  
FUEL FLOW RATE, LBS/MIN 3.234  
FUEL/AIR RATIO 0.2151  
AIR FLOW LOADING FACTOR 1.6869

FUEL PRESSURE=0  
FUEL TEMPERATURE=121.1 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

DOT AVG=1728.2 DEG F  
DOT HOT SPOT: TCB 6 = 1856 DEG F  
DOT PATTERN FACTOR = .1138

OUTER ANNULUS	TCB	AVERAGE	STD DEV
1	1821	16	16
2	1879	37	37
3	1661	0	0
4	1650	14	14
5	1798	25	25
6	1798	16	16
7	1856	11	11
8	1639	12	12
9	1774	10	10
10	1626	19	19
11	1626	26	26
12	1798	130	130
13	1798	15	15

\* EXHAUST CHEMISTRY \*

CO.. .833 % CO2..4.52 % O2..14.6 % UH.. 3.4 PPM (PROPANE)  
NO.. 51.7 PPM NOX.. 59.5 PPM NO2.. 7.8 PPM (NOX-NO)  
SMOKE NUMBER: 21.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6193 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021596  
REMARKS: 3000 P.S.I. 2% avg.

Figure 20 - Test Report of Experiment No. 13

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY

100% OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*  
U.S. ARMY AIR ENGINEERING CENTER

DATE: 6/25/75 TIME: 11:46  
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JPS-P EMULSIFIED WITH 5% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.53  
INLET AIR TEMPERATURE, DEG F 524.96  
AIR FLOW RATE, LBS/SEC 2.503  
FUEL FLOW RATE, LBS/MIN 3.166  
FUEL/AIR RATIO .02100  
AIR FLOW LOADING FACTOR 1.6963

FUEL PRESSURE=0  
FUEL TEMPERATURE=125.4 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

DOT AVG=1626.3 DEG F  
DOT HOT SPOT: TCB 8 = 1925 DEG F  
DOT PATTERN FACTOR = .1899

OUTER ANNULUS	TCB	AVERAGE	STD DEV
1	1784	14	14
2	1582	34	34
3	1590	11	11
4	1590	15	15
5	1587	36	36
6	1771	14	14
7	1825	322	322
8	1688	11	11
9	1747	13	13
10	1747	11	11
11	1747	10	10
12	1771	12	12
13	1771	31	31
14	1771	162	162
15	1771	15	15

\* EXHAUST CHEMISTRY \*

CO.. .835 % CO2..4.40 % O2..14.5 % UH.. 3.6 PPM (PROPANE)  
NO.. 50.5 PPM NOX.. 57.5 PPM NO2.. 7.0 PPM (NOX-NO)  
SMOKE NUMBER: 23.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5872 %  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021314  
REMARKS: 3000 P.S.I. 1% avg.

Figure 21 - Test Report of Experiment No. 14

# U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/25/75  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 5% WATER  
TIME: 12:32  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 72.31  
INLET AIR TEMPERATURE, DEG F 524.35  
AIR FLOW RATE, LBS/SEC 2.494  
FUEL FLOW RATE, LBS/MIN 3.166  
FUEL/AIR RATIO .02116  
AIR FLOW LOADING FACTOR 1.0819  
DESIRED 76.20  
1.26  
2.660  
3.160  
.02090  
1.0940  
LAST SCAN 72.10  
524.76  
2.482  
3.188  
.02135  
1.0884

FUEL PRESSURE= 0  
FUEL TEMPERATURE=125.0 DEG F

## \* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1697.1 DEG F  
BOT HOT SPOT: TCR 8 = 1822 DEG F  
BOT PATTERN FACTOR = .1157

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1	1763	21
4	4	1576	28
7	7	0	14
10	10	1565	29
13	13	1586	17
16	16	1771	21
CENTER ANNULUS	5	0	2386
8	8	1822	11
11	11	1594	13
14	14	1742	10
INNER ANNULUS	3	0	11
6	6	0	12
9	9	0	119
12	12	0	58
15	15	1765	14

## \* EXHAUST CHEMISTRY \*

CO... .035 % CO2...4.37 % O2...14.3 % UHM... 3.6 PPM (PROPANE)  
NO... 52.5 PPM NOX... 58.5 PPM NO2... 6.0 PPM (NOX-NO)  
SMOKE NUMBER: 24.0

CALCULATION: EFFICIENCY: CALCULATED FROM EXHAUST CHEMISTRY: 99.5938 %  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .021470

REMARKS: 3000 P.S.I. 4% and

Figure 22 - Test Report of Experiment No. 15

# U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/27/75  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HA EMULSIFIED WITH 0% WATER  
TIME: 9:24  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.54  
INLET AIR TEMPERATURE, DEG F 524.98  
AIR FLOW RATE, LBS/SEC 2.498  
FUEL FLOW RATE, LBS/MIN 2.980  
FUEL/AIR RATIO .01988  
AIR FLOW LOADING FACTOR 1.0960  
DESIRED 76.20  
1.32  
2.660  
3.160  
.02026  
1.0950  
LAST SCAN 71.60  
524.11  
2.518  
3.027  
.02018  
1.0996

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 89.7 DEG F

## \* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1700.5 DEG F  
BOT HOT SPOT: TCR 8 = 1823 DEG F  
BOT PATTERN FACTOR = .1042

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1	1791	12
4	4	1730	17
7	7	0	4
10	10	1629	11
13	13	1648	10
16	16	1773	12
CENTER ANNULUS	2	0	12
5	5	1716	12
8	8	1823	10
11	11	1593	12
14	14	1741	10
INNER ANNULUS	3	0	11
6	6	0	16
9	9	1682	10
12	12	0	9
15	15	1782	16

## \* EXHAUST CHEMISTRY \*

CO... .033 % CO2...4.42 % O2...15.0 % UHM... 2.5 PPM (PROPANE)  
NO... 60.5 PPM NOX... 66.5 PPM NO2... 6.0 PPM (NOX-NO)  
SMOKE NUMBER: 33.6

CALCULATION: EFFICIENCY: CALCULATED FROM EXHAUST CHEMISTRY: 99.6089 %  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .020755

REMARKS:

Figure 23 - Test Report of Experiment No. 16

NAVY FUELS & LIQUIDANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
NAVY OF THE EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

TEST FUEL: JPS-WATERULSIFIED WITH 0% WATER  
TIME: 111.0  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 70.65 75.20 71.20  
INLET AIR TEMPERATURE, DEG F 522.95 524.00 519.36  
AIR FLOW RATE, LBS/SEC 2.487 .013 2.669 2.497  
FUEL FLOW RATE, LBS/MIN 2.983 .049 3.160 3.000  
FUEL/AIR RATIO .01999 .00035 .01900 .02002  
AIR FLOW LOADING FACTOR 1.1037 .0112 1.0940 1.0976

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 90.4 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1673.3 DEG F  
BOT HOT SPOT: TCB 8 = 1804 DEG F  
BOT PATTERN FACTOR = .1137

OUTER ANNULUS TCB AVERAGE STD DEV

1 1784 21  
4 1652 29  
7 21 21  
10 1552 30  
13 1641 14  
16 1778 21  
19 1610 71

CENTER ANNULUS

5 1804 16  
8 1577 17  
11 1736 13  
14 1540 16  
17 125 125  
20 28 28  
23 1732 15

INNER ANNULUS

3 1540 16  
6 125 125  
9 28 28  
12 1732 15

\* EXHAUST CHEMISTRY \*

CO<sub>2</sub> .436 % CO<sub>2</sub> 4.36 % O<sub>2</sub> 14.9 % URM . 3.2 PPM (PROPANE)

NO<sub>x</sub> 52.5 PPM NO<sub>x</sub> 60.0 PPM NO<sub>2</sub> 7.5 PPM (NOX-HO)

SAMPLE NUMBER: 2.5.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.3761 %

FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020775

REMARKS:

Figure 25 - Test Report of Experiment No. 18

NAVY FUELS & LIQUIDANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
NAVY OF THE EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

TEST FUEL: JPS-WATERULSIFIED WITH 10% WATER  
TIME: 91.57  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.35 76.20 71.90  
INLET AIR TEMPERATURE, DEG F 525.60 524.00 525.84  
AIR FLOW RATE, LBS/SEC 2.436 .012 2.660 2.460  
FUEL FLOW RATE, LBS/MIN 3.259 .032 3.360 3.267  
FUEL/AIR RATIO .02212 .00025 .02220 .02213  
AIR FLOW LOADING FACTOR 1.0944 .0067 1.0940 1.0742

FUEL PRESSURE= 0  
FUEL TEMPERATURE= 120.7 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1596.7 DEG F  
BOT HOT SPOT: TCB 8 = 1854 DEG F  
BOT PATTERN FACTOR = .1341

OUTER ANNULUS TCB AVERAGE STD DEV

1 1792 13  
4 1687 20  
7 2 2  
10 1596 14  
13 1659 11  
16 1763 13  
19 1731 12  
22 1854 8  
25 1215 13  
28 1747 10  
31 1577 12  
34 153 153  
37 1593 13  
40 1720 12

CENTER ANNULUS

5 1731 12  
8 1854 8  
11 1215 13  
14 1747 10  
17 1577 12  
20 153 153  
23 1593 13  
26 1720 12

INNER ANNULUS

3 1577 12  
6 153 153  
9 1593 13  
12 1720 12

\* EXHAUST CHEMISTRY \*

CO<sub>2</sub> .439 % CO<sub>2</sub> 4.40 % O<sub>2</sub> 14.5 % URM . 5.3 PPM (PROPANE)

NO<sub>x</sub> 48.3 PPM NO<sub>x</sub> 54.5 PPM NO<sub>2</sub> 6.0 PPM (NOX-HO)

SAMPLE NUMBER: 2.3.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.3266 %

FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021304

REMARKS:

3000 P.S.I. 2% avg.

Figure 24 - Test Report of Experiment No. 17

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES -  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-20-75  
COMBUSTION SYSTEM: T-63  
TEST FUEL: JPS-HOREMULSIFIED WITH 10% WATER  
TIME: 11:0  
POWER POINT: 100%  
0% WATER  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.60  
INLET AIR TEMPERATURE, DEG F 524.34  
AIR FLOW RATE, LBS/SEC 2.474  
FUEL FLOW RATE, LBS/MIN 3.300  
FUEL/AIR RATIO .0223  
AIR FLOW LOADING FACTOR 1.0940  
DESIRED 76.20  
7.50  
524.11  
2.468  
3.360  
0.0228  
1.0940  
LAST SCAN  
AVERAGE STD. DEV.  
26  
1.46  
0.13  
0.039  
0.0033  
0.0073

FUEL PRESSURE=0  
FUEL TEMPERATURE=121.1 DEG F  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.60  
INLET AIR TEMPERATURE, DEG F 524.34  
AIR FLOW RATE, LBS/SEC 2.474  
FUEL FLOW RATE, LBS/MIN 3.300  
FUEL/AIR RATIO .0223  
AIR FLOW LOADING FACTOR 1.0940  
DESIRED 76.20  
7.50  
524.11  
2.468  
3.360  
0.0228  
1.0940  
LAST SCAN  
AVERAGE STD. DEV.  
26  
1.46  
0.13  
0.039  
0.0033  
0.0073

BOT AVG=1632.5 DEG F  
BOT HOT SPOT: TCR 9 = 1817 DEG F  
BOT PATTERN FACTOR = .1459  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.60  
INLET AIR TEMPERATURE, DEG F 524.34  
AIR FLOW RATE, LBS/SEC 2.474  
FUEL FLOW RATE, LBS/MIN 3.300  
FUEL/AIR RATIO .0223  
AIR FLOW LOADING FACTOR 1.0940  
DESIRED 76.20  
7.50  
524.11  
2.468  
3.360  
0.0228  
1.0940  
LAST SCAN  
AVERAGE STD. DEV.  
26  
1.46  
0.13  
0.039  
0.0033  
0.0073

CO... 041.2 % CO2... 4.40 % O2... 14.7 % UN... 5.4 PPM (PROPANE)  
NO... 45.8 PPM NOX... 51.6 PPM NO2... 6.6 PPM (NOX-NO)  
SMOKE NUMBER: 15.4  
CONSUMPTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5011 %  
3000 P.S.I. 2% *anf.*

Figure 26 - Test Report of Experiment No. 19

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES -  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-17-75  
COMBUSTION SYSTEM: T-63  
TEST FUEL: JPS-P  
TIME: 9:27  
POWER POINT: 100%  
0% WATER  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 66.63  
INLET AIR TEMPERATURE, DEG F 523.42  
AIR FLOW RATE, LBS/SEC 2.339  
FUEL FLOW RATE, LBS/MIN 2.810  
FUEL/AIR RATIO .02002  
AIR FLOW LOADING FACTOR 1.0975  
DESIRED 76.20  
65.90  
523.46  
2.366  
2.810  
0.0190  
1.0940  
LAST SCAN  
AVERAGE STD. DEV.  
49  
1.14  
0.12  
0.024  
0.0019  
0.0093

FUEL PRESSURE=305  
FUEL TEMPERATURE=137.5 DEG F  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 66.63  
INLET AIR TEMPERATURE, DEG F 523.42  
AIR FLOW RATE, LBS/SEC 2.339  
FUEL FLOW RATE, LBS/MIN 2.810  
FUEL/AIR RATIO .02002  
AIR FLOW LOADING FACTOR 1.0975  
DESIRED 76.20  
65.90  
523.46  
2.366  
2.810  
0.0190  
1.0940  
LAST SCAN  
AVERAGE STD. DEV.  
49  
1.14  
0.12  
0.024  
0.0019  
0.0093

BOT AVG=1632.5 DEG F  
BOT HOT SPOT: TCR 9 = 1817 DEG F  
BOT PATTERN FACTOR = .1459  
\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 71.60  
INLET AIR TEMPERATURE, DEG F 524.34  
AIR FLOW RATE, LBS/SEC 2.474  
FUEL FLOW RATE, LBS/MIN 3.300  
FUEL/AIR RATIO .0223  
AIR FLOW LOADING FACTOR 1.0940  
DESIRED 76.20  
7.50  
524.11  
2.468  
3.360  
0.0228  
1.0940  
LAST SCAN  
AVERAGE STD. DEV.  
26  
1.46  
0.13  
0.039  
0.0033  
0.0073

CO... 036 % CO2... 4.50 % O2... 14.5 % UN... 9.4 PPM (PROPANE)  
NO... 55.5 PPM NOX... 62.0 PPM NO2... 6.5 PPM (NOX-NO)  
SMOKE NUMBER: 29.7  
CONSUMPTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5442  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .001283

Figure 27 - Test Report of Experiment No. 20



U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*

DATE: 6/17/76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JP5-P EMULSIFIED WITH 15% WATER  
TIME: 11:2  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 67.16  
INLET AIR TEMPERATURE, DEG F 524.88  
AIR FLOW RATE, LBS/SEC 3.194  
FUEL FLOW RATE, LBS/MIN 0.2297  
FUEL/AIR RATIO 0.0623  
AIR FLOW LOADING FACTOR 1.0629  
DESIRED 65.48  
1.17  
524.09  
2.348  
3.250  
0.2230  
1.0740  
LAST SCAN 67.20  
524.11  
2.310  
3.231  
0.2331  
1.0782

FUEL PRESSURE= 360  
FUEL TEMPERATURE=133.6 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1740.0 DEG F  
BOT HOT SPOT: TCG 2 = 1893 DEG F  
BOT PATTERN FACTOR = .1256

TCR	AVERAGE	STD DEV
OUTER ANNULUS	1538	15
1	1635	40
4	1635	20
7	1635	27
10	1593	15
13	1873	15
16	1800	16
19	1807	12
22	1621	13
25	1621	10
28	1709	10
31	1621	10
34	1635	15
37	1615	29
40	1823	10

\* EXHAUST CHEMISTRY \*

CO.. .844 % CO2..4.55 % O2..14.7 % UHM.5.4 PPM (PROPANE)  
NO.. 44.0 PPM NOX.. 52.3 PPM NO2.. 8.3 PPM (NOX-NO)  
SMOKE NUMBER: 17.6

COMBUSTION EFFICIENCY: CALCULATED FROM EXHAUST CHEMISTRY: 99.4076  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .021638  
REMARKS:

Figure 30 - Test Report of Experiment No. 23

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*

DATE: 6/17/76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JP5-P EMULSIFIED WITH 20% WATER  
TIME: 11:43  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 66.82  
INLET AIR TEMPERATURE, DEG F 524.32  
AIR FLOW RATE, LBS/SEC 2.311  
FUEL FLOW RATE, LBS/MIN 3.302  
FUEL/AIR RATIO 0.0624  
AIR FLOW LOADING FACTOR 1.0854  
DESIRED 65.48  
1.17  
524.09  
2.348  
3.300  
0.1200  
1.0940  
LAST SCAN 67.80  
524.97  
2.289  
3.385  
0.2407  
1.0995

FUEL PRESSURE= 370  
FUEL TEMPERATURE=135.3 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1712.3 DEG F  
BOT HOT SPOT: TCG 2 = 1833 DEG F  
BOT PATTERN FACTOR = .1019

TCR	AVERAGE	STD DEV
OUTER ANNULUS	1792	11
1	1704	33
4	1704	62
7	1569	60
10	1833	26
13	1833	11
16	1761	13
19	1768	12
22	1637	13
25	1637	0
28	1820	14
31	1599	203
34	1599	13
37	1558	27
40	1770	11

\* EXHAUST CHEMISTRY \*

CO.. .852 % CO2..4.35 % O2..15.0 % UHM.11.4 PPM (PROPANE)  
NO.. 33.0 PPM NOX.. 41.5 PPM NO2.. 0.5 PPM (NOX-NO)  
SMOKE NUMBER: 14.7

COMBUSTION EFFICIENCY: CALCULATED FROM EXHAUST CHEMISTRY: 98.3549  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .009732  
REMARKS:

Figure 31 - Test Report of Experiment No. 24

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-18-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P  
TIME: 9:19  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 67.04  
INLET AIR TEMPERATURE, DEG F 526.91  
AIR FLOW RATE, LBS/SEC 2.336  
FUEL FLOW RATE, LBS/MIN 2.754  
FUEL/AIR RATIO .81965  
AIR FLOW LOADING FACTOR 1.0948  
DESIRED 65.48  
524.00  
2.340  
3.668  
.82370  
1.0948  
LAST SCAN 67.60  
526.92  
2.335  
2.748  
.81962  
1.0950

FUEL PRESSURE= 320  
FUEL TEMPERATURE=133.6 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1714.6 DEG F  
BOT HOT SPOT: TCG 2 = 1950 DEG F  
BOT PATTERN FACTOR = .1139

OUTER ANNULUS TCG AVERAGE STD DEV  
1 1767 13  
4 1636 85  
7 1553 22  
10 1612 10  
13 1632 10  
16 1858 13  
19 1753 14

CENTER ANNULUS  
5 1752 9  
8 1710 14  
11 1711 10  
14 1725 13  
17 1825 17  
20 1675 12  
23 1668 15  
26 1800 12

INNER ANNULUS  
3 1825 13  
6 1675 12  
9 1668 15  
12 1800 12

\* EXHAUST CHEMISTRY \*

CO... .039 % CO2...4.32 % O2...15.2 % UHM...3.6 PPM (PROPANE)  
NO... 50.3 PPM NOX... 60.5 PPM NO2...10.2 PPM (NOX-NO)  
SMOKE NUMBER: 29.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5348  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .800382  
REMARKS:

Figure 33 - Test Report of Experiment No. 26

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-17-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 25% METHANOL/WATER  
TIME: 12:10  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 63.39  
INLET AIR TEMPERATURE, DEG F 524.05  
AIR FLOW RATE, LBS/SEC 2.312  
FUEL FLOW RATE, LBS/MIN 3.489  
FUEL/AIR RATIO .82516  
AIR FLOW LOADING FACTOR 1.1091  
DESIRED 65.40  
524.00  
2.340  
3.520  
.82480  
1.0940  
LAST SCAN 65.20  
524.11  
2.327  
3.445  
.82470  
1.1196

FUEL PRESSURE= 390  
FUEL TEMPERATURE=134.5 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1782.3 DEG F  
BOT HOT SPOT: TCG 3 = 1821 DEG F  
BOT PATTERN FACTOR = .1095

OUTER ANNULUS TCG AVERAGE STD DEV  
1 1786 13  
4 1703 36  
7 1703 73  
10 1509 22  
13 1829 13  
16 1751 12  
19 1758 12  
22 1642 10  
25 1725 16  
28 1831 15  
31 1502 26  
34 1590 11  
37 1542 29  
40 1765 12

CENTER ANNULUS  
5 1751 12  
8 1758 12  
11 1642 10  
14 1725 16  
17 1831 15  
20 1502 26  
23 1590 11  
26 1542 29  
29 1765 12

INNER ANNULUS  
3 1831 15  
6 1502 26  
9 1590 11  
12 1542 29  
15 1765 12

\* EXHAUST CHEMISTRY \*

CO... .038 % CO2...4.35 % O2...14.7 % UHM...14.7 PPM (PROPANE)  
NO... 39.5 PPM NOX... 38.3 PPM NO2... 8.8 PPM (NOX-NO)  
SMOKE NUMBER: 12.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.2448  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .821083  
REMARKS:

Figure 32 - Test Report of Experiment No. 25

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/8/76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JP5-P EMULSIFIED WITH 5% WATER

TIME: 9:38  
POWER POINT: 100%  
TEST FUEL: JP5-P EMULSIFIED WITH 30% WATER

\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*

INLET AIR PRESSURE, PSIA	INLET AIR TEMPERATURE, DEG F	AIR FLOW RATE, LBS/SEC	FUEL FLOW RATE, LBS/MIN	FUEL/AIR RATIO	AIR FLOW LOADING FACTOR	DESIRED	LAST SCAN
66.95	526.48	2.331	2.947	.0217	1.0935	66.95	66.95
526.48	527.13	2.331	2.947	.0217	1.0935	526.48	526.48
10.200	2.323	10.200	2.323	10.200	2.323	10.200	10.200
.014	.014	.014	.014	.014	.014	.014	.014
.0022	.0022	.0022	.0022	.0022	.0022	.0022	.0022
.0072	.0072	.0072	.0072	.0072	.0072	.0072	.0072

FUEL PRESSURE= 340  
FUEL TEMPERATURE=134.9 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

DOT AVG=1724.0 DEG F  
DOT HOT SPOT: TCG 2 = 1841 DEG F  
DOT PATTERN FACTOR = .0971

OUTER ANNULUS	TCG	AVERAGE	STD DEV
1	1768	14	14
4	1538	45	45
7	1590	9	9
10	1631	10	10
13	1841	14	14
16	1700	12	12
19	1704	11	11
22	1721	12	12
25	1760	13	13
28	1835	37	37
31	1681	10	10
34	1676	25	25
37	1793	16	16

\* EXHAUST CHEMISTRY \*

CO.. .046 % CO2..4.40 % O2..14.8 % UHM..6.3 PPM PROPANE  
NO.. 45.3 PPM NOX.. 55.0 PPM NO2.. 8.7 PPM (NOX-NO)  
SMOKE NUMBER: 22.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.4528  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021060  
REMARKS:

Figure 34 - Test Report of Experiment No. 27

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/8/76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JP5-P EMULSIFIED WITH 30% WATER

TIME: 10:0

POWER POINT: 100%

\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*

INLET AIR PRESSURE, PSIA	INLET AIR TEMPERATURE, DEG F	AIR FLOW RATE, LBS/SEC	FUEL FLOW RATE, LBS/MIN	FUEL/AIR RATIO	AIR FLOW LOADING FACTOR	DESIRED	LAST SCAN
67.07	527.65	2.330	3.615	.0222	1.0919	67.07	66.80
527.65	527.65	2.330	3.615	.0222	1.0919	527.65	526.48
1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
.012	.012	.012	.012	.012	.012	.012	.012
.0022	.0022	.0022	.0022	.0022	.0022	.0022	.0022
.0068	.0068	.0068	.0068	.0068	.0068	.0068	.0068

FUEL PRESSURE= 415  
FUEL TEMPERATURE=125.0 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

DOT AVG=1710.4 DEG F  
DOT HOT SPOT: TCG 2 = 1804 DEG F  
DOT PATTERN FACTOR = .0792

OUTER ANNULUS	TCG	AVERAGE	STD DEV
1	1741	11	11
4	1705	26	26
7	1596	12	12
10	1610	11	11
13	1804	11	11
16	1731	12	12
19	1713	11	11
22	1719	13	13
25	1730	11	11
28	1791	13	13
31	1665	30	30
34	1681	12	12
37	1751	14	14
40	1751	11	11

\* EXHAUST CHEMISTRY \*

CO.. .063 % CO2..4.30 % O2..15.0 % UHM..20.0 PPM PROPANE  
NO.. 26.3 PPM NOX.. 34.4 PPM NO2.. 8.1 PPM (NOX-NO)  
SMOKE NUMBER: 12.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.1670  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020035  
REMARKS:

Figure 35 - Test Report of Experiment No. 28

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U. S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/78  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JP5-P

TIME: 1215  
POWER POINT: 25%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 45.37 DESIRED 45.10  
INLET AIR TEMPERATURE, DEG F 352.56 353.00  
AIR FLOW RATE, LBS/SEC 1.806 1.810  
FUEL FLOW RATE, LBS/MIN 1.311 1.310  
FUEL/AIR RATIO .01210 .01210  
AIR FLOW LOADING FACTOR 1.1345 .0134 1.1450  
LAST SCAN 45.30 352.56 1.796 1.324 .01226 1.1300

FUEL PRESSURE= 100  
FUEL TEMPERATURE=157.4 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1133.1 DEG F  
BOT HOT SPOT: TCR 2 = 1256 DEG F  
BOT PATTERN FACTOR = .1569  
OUTER ANNULUS TCR AVERAGE STD DEV  
1 1179 10  
4 1127 20  
7 0 25  
10 0 6  
13 1026 7  
16 1256 10  
19 1135 12  
22 1158 8  
25 1041 8  
28 1124 7  
31 1236 11  
34 0 43  
37 1102 8  
40 1036 12  
43 1177 10

\* EXHAUST CHEMISTRY \*

CO.. .096 % CO2..2.54 % O2..17.5 % UHM.. 140.0 PPM (PROPANE)  
NO.. 11.7 PPM NOX.. 19.3 PPM NO2.. 7.6 PPM (NOX-NO)  
SHAKE NUMBER: 14.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.733  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .012006  
REMARKS:

Figure 37 - Test Report of Experiment No. 30

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U. S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/78  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JP5-P EMULSIFIED WITH 40% WATER

TIME: 10:39  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 66.12 DESIRED 65.40  
INLET AIR TEMPERATURE, DEG F 527.66 524.00  
AIR FLOW RATE, LBS/SEC 2.325 2.340  
FUEL FLOW RATE, LBS/MIN 3.093 3.090  
FUEL/AIR RATIO .02792 .02770  
AIR FLOW LOADING FACTOR 1.1053 .0066 1.0940  
LAST SCAN 66.40 525.84 3.344 3.930 .02794 1.1085

FUEL PRESSURE= 445  
FUEL TEMPERATURE=122.8 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1694.0 DEG F  
BOT HOT SPOT: TCR 3 = 1770 DEG F  
BOT PATTERN FACTOR = .0742  
OUTER ANNULUS TCR AVERAGE STD DEV  
1 1721 13  
4 1649 33  
7 0 38  
10 1585 13  
13 1562 16  
16 1769 13  
19 1722 14  
22 1782 13  
25 1694 12  
28 1709 13  
31 1770 15  
34 0 60  
37 1630 19  
40 1647 17  
43 1732 14

\* EXHAUST CHEMISTRY \*

CO.. .073 % CO2..4.33 % O2..15.0 % UHM.. 30.7 PPM (PROPANE)  
NO.. 20.5 PPM NOX.. 25.5 PPM NO2.. 9.0 PPM (NOX-NO)  
SHAKE NUMBER: 10.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 90.0028  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .009773  
REMARKS:

Figure 36 - Test Report of Experiment No. 29

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 5-18-76 TIME: 12143  
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%  
TEST FUEL: JPS-P EMULSIFIED WITH 10% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

INLET AIR PRESSURE, PSIA	AVERAGE STD. DEV.	DESIRED	LAST SCAN
44.84	.18	45.10	44.70
INLET AIR TEMPERATURE, DEG F	351.75	353.00	352.50
AIR FLOW RATE, LBS/SEC	1.810	1.810	1.804
FUEL FLOW RATE, LBS/MIN	1.418	1.448	1.413
FUEL/AIR RATIO	.01306	.01330	.01305
AIR FLOW LOADING FACTOR	1.1498	1.1450	1.1505

FUEL PRESSURE= 192  
FUEL TEMPERATURE=152.6 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

ROT AVG=1127.5 DEG F  
ROT HOT SPOT: TCR 3 = 1254 DEG F  
ROT PATTERN FACTOR = .1626

	TCR	AVERAGE		STD DEV
		1	2	
OUTER ANNULUS	1	1166	18	11
	4	1162	10	6
	7	1035	6	11
	10	0	0	0
	13	1034	14	6
CENTER ANNULUS	2	1246	14	12
	5	1144	12	11
	8	1148	11	9
	11	1036	9	10
	14	1122	10	12
INNER ANNULUS	3	1254	12	8
	6	1131	8	10
	9	1102	9	9
	12	1039	9	12
	15	1168	12	12

\* EXHAUST CHEMISTRY \*

CO.. .122 % CO2..2.50 % O2..17.3 % UHM. 233.3 PPH (PROPANE)  
NO.. 12.3 PPH NOX.. 17.0 PPH NO2.. 4.7 PPH (NOX-HO)  
SMOKE NUMBER: 8.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.0419  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .01303  
REMARKS:

Figure 38 - Test Report of Experiment No. 31

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 5-18-76 TIME: 11:3  
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%  
TEST FUEL: JPS-P EMULSIFIED WITH 20% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

INLET AIR PRESSURE, PSIA	AVERAGE STD. DEV.	DESIRED	LAST SCAN
44.57	.18	45.10	44.60
INLET AIR TEMPERATURE, DEG F	351.81	353.00	352.07
AIR FLOW RATE, LBS/SEC	1.805	1.810	1.805
FUEL FLOW RATE, LBS/MIN	1.564	1.570	1.567
FUEL/AIR RATIO	.01444	.01450	.01447
AIR FLOW LOADING FACTOR	1.1536	1.1450	1.1532

FUEL PRESSURE= 200  
FUEL TEMPERATURE=148.3 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

ROT AVG=1113.9 DEG F  
ROT HOT SPOT: TCR 3 = 1239 DEG F  
ROT PATTERN FACTOR = .1645

	TCR	AVERAGE		STD DEV
		1	2	
OUTER ANNULUS	1	1138	11	11
	4	1150	11	11
	7	1050	9	14
	10	0	0	0
	13	1007	7	11
CENTER ANNULUS	2	1224	11	11
	5	1139	9	13
	8	1136	13	9
	11	1016	9	8
	14	1095	12	7
INNER ANNULUS	3	1233	12	8
	6	1127	7	7
	9	1100	8	7
	12	1021	7	10
	15	1142	10	10

\* EXHAUST CHEMISTRY \*

CO.. .135 % CO2..2.50 % O2..17.3 % UHM. 327.7 PPH (PROPANE)  
NO.. 10.7 PPH NOX.. 13.7 PPH NO2.. 3.6 PPH (NOX-HO)  
SMOKE NUMBER: 5.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.0660  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .015004  
REMARKS:

Figure 39 - Test Report of Experiment No. 32

NAEC-92-114

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-18-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 40% WATER  
TIME: 1:46  
POWER POINT: 25%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

	AVERAGE	STD. DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.87	.13	45.10	44.80
INLET AIR TEMPERATURE, DEG F	352.60	.62	353.00	352.50
AIR FLOW RATE, LBS/SEC	1.795	.011	1.810	1.792
FUEL FLOW RATE, LBS/MIN	1.797	.014	1.830	1.794
FUEL/AIR RATIO	.01660	.00017	.01650	.01669
AIR FLOW LOADING FACTOR	1.1466	.00075	1.1450	1.1399

FUEL PRESSURE= 213  
FUEL TEMPERATURE=139.2 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1096.4 DEG F  
BOT HOT SPOT: TCR 3 = 1217 DEG F  
BOT PATTERN FACTOR = .1720

	AVERAGE	STD DEV
OUTER ANNULUS	1081	12
	1150	10
	1024	5
	1012	6
	0	5
CENTER ANNULUS	1173	12
	1100	9
	1082	9
	1004	8
	1063	6
INNER ANNULUS	1217	12
	1086	6
	1084	8
	0	6
	1100	8

\* EXHAUST CHEMISTRY \*

CO... .152 % CO2...2.49 % O2...17.5 % UCH...468.0 PPM PROPANE  
NO... .0.0 PPM NOX... 9.7 PPM NO2... 1.7 PPM (NOX+NO)  
SAMPLE NUMBER: 3.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: .92.1171  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .012847  
REMARKS:

Figure 41 - Test Report of Experiment No. 34

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-18-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 30% WATER  
TIME: 1:23  
POWER POINT: 25%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

	AVERAGE	STD. DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.90	.17	45.10	44.80
INLET AIR TEMPERATURE, DEG F	352.66	.66	353.00	352.07
AIR FLOW RATE, LBS/SEC	1.801	.011	1.810	1.789
FUEL FLOW RATE, LBS/MIN	1.666	.015	1.703	1.650
FUEL/AIR RATIO	.00918	.00018	.01570	.01344
AIR FLOW LOADING FACTOR	1.1432	.00088	1.1450	1.1383

FUEL PRESSURE= 205  
FUEL TEMPERATURE=141.0 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1079.5 DEG F  
BOT HOT SPOT: TCR 3 = 1217 DEG F  
BOT PATTERN FACTOR = .1895

	AVERAGE	STD DEV
OUTER ANNULUS	1093	12
	1143	11
	1028	7
	995	7
	983	6
CENTER ANNULUS	1106	12
	1110	11
	1091	10
	998	8
	1066	7
INNER ANNULUS	1217	11
	1087	9
	1082	9
	997	8
	1105	9

\* EXHAUST CHEMISTRY \*

CO... .142 % CO2...2.40 % O2...17.4 % UCH...393.7 PPM PROPANE  
NO... .8.6 PPM NOX... 11.3 PPM NO2... 2.5 PPM (NOX+NO)  
SAMPLE NUMBER: 4.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: .93.0344  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .012759  
REMARKS:

Figure 40 - Test Report of Experiment No. 33

U. S. ARMY FUELS & OILS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76  
COMBUSTION SYSTEM: T-63  
TEST FUEL: JPS-P  
TIME: 10: 3  
POWER POINT: 100%

\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*  
INLET A/P PRESSURE, PSIA 69.49  
INLET AIR TEMPERATURE, DEG F 525.12  
AIR FLOW RATE, LBS/SEC 2.375  
FUEL FLOW RATE, LBS/MIN 2.839  
FUEL/AIR RATIO .01992  
AIR FLOW LOADING FACTOR 1.0883  
DESIRED 65.40  
STD. DEV. .19  
3.98  
.014  
2.826  
.0023  
.0053  
LAST SCAN 58.50  
525.84  
2.388  
2.831  
.01975  
1.0948

FUEL PRESSURE= 318  
FUEL TEMPERATURE=126.7 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1719.1 DEG F  
BOT HOT SPOT: TCR 2 = 1850 DEG F  
BOT PATTERN FACTOR = .1095  
OUTER ANNULUS  
1 1753  
4 1719  
7 1680  
10 1559  
13 1592  
CENTER ANNULUS  
2 1858  
5 1773  
8 1792  
11 1679  
14 1730  
INNER ANNULUS  
3 1845  
6 1676  
9 1785  
12 1652  
15 1700  
STD DEV  
13  
28  
23  
10  
12  
13  
17  
14  
10  
14  
34  
13  
12  
12

\* EXHAUST CHEMISTRY \*

CO.. .036 % CO2..4.35 % O2..15.1 % UHM..3.5 PPM (PROPANE)  
NO.. 56.8 PPM NOX.. 61.7 PPM NO2.. 5.7 PPM (NOX-NO)  
SMOKE NUMBER: 28.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5485  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020544

Figure 42 - Test Report of Experiment No. 35

U. S. ARMY FUELS & OILS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76  
COMBUSTION SYSTEM: T-63  
TEST FUEL: JPS-P ENULSIFIED WITH 40% WATER  
TIME: 10:34  
POWER POINT: 100%

\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*  
INLET A/P PRESSURE, PSIA 67.82  
INLET AIR TEMPERATURE, DEG F 526.71  
AIR FLOW RATE, LBS/SEC 2.367  
FUEL FLOW RATE, LBS/MIN 3.971  
FUEL/AIR RATIO .02796  
AIR FLOW LOADING FACTOR 1.0962  
DESIRED 65.40  
STD. DEV. .26  
2.83  
.018  
2.340  
.023  
.0270  
LAST SCAN 68.38  
531.45  
2.346  
4.818  
0.2854  
1.0817

FUEL PRESSURE= 435  
FUEL TEMPERATURE=110.1 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1678.4 DEG F  
BOT HOT SPOT: TCR 2 = 1796 DEG F  
BOT PATTERN FACTOR = .1023  
OUTER ANNULUS  
1 1717  
4 1666  
7 1649  
10 1536  
13 1582  
CENTER ANNULUS  
2 1796  
5 1753  
8 1725  
11 1693  
14 1763  
INNER ANNULUS  
3 1763  
6 1534  
9 1668  
12 1651  
15 1739  
STD DEV  
10  
29  
10  
10  
9  
10  
12  
13  
9  
15  
141  
10  
11  
10

\* EXHAUST CHEMISTRY \*

CO.. .070 % CO2..4.48 % O2..14.7 % UHM..25.5 PPM (PROPANE)  
NO.. 25.8 PPM NOX.. 31.0 PPM NO2.. 6.8 PPM (NOX-NO)  
SMOKE NUMBER: 9.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.0824  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021270

Figure 43 - Test Report of Experiment No. 36

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 8-21-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR

DATE: 8-21-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-P EMULSIFIED WITH 50% WATER

TIME: 2:25  
POWER POINT: 100%

TIME: 10:53  
POWER POINT: 100%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 66.16  
INLET AIR TEMPERATURE, DEG F 527.47  
AIR FLOW RATE, LBS/SEC 2.310  
FUEL FLOW RATE, LBS/MIN 2.768  
FUEL/AIR RATIO .01960  
AIR FLOW LOADING FACTOR 1.0970  
DESIRED LAST SCAN  
AVERAGE STD. DEV. 65.48  
66.10  
524.08  
2.280  
2.768  
.01961  
1.0923

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 68.39  
INLET AIR TEMPERATURE, DEG F 526.14  
AIR FLOW RATE, LBS/SEC 2.358  
FUEL FLOW RATE, LBS/MIN 4.239  
FUEL/AIR RATIO .02997  
AIR FLOW LOADING FACTOR 1.0825  
DESIRED LAST SCAN  
AVERAGE STD. DEV. 55.48  
59.60  
527.35  
2.373  
4.246  
.02981  
1.0871

FUEL PRESSURE= 300  
FUEL TEMPERATURE=137.1 DEG F

FUEL PRESSURE= 470  
FUEL TEMPERATURE=114.6 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1682.8 DEG F  
BOT HOT SPOT: TCG 9 = 1790 DEG F  
BOT PATTERN FACTOR = .0932  
OUTER ANNULUS TCG AVERAGE STD DEV  
1 1678 12  
4 1675 39  
7 1614 45  
10 1564 19  
13 1579 9  
16 1786 12  
19 1743 13  
22 1790 14  
25 1662 14  
28 1692 11  
31 1772 15  
34 1630 103  
37 1696 11  
40 1634 13  
43 1728 11

BOT AVG=1669.4 DEG F  
BOT HOT SPOT: TCG 2 = 1763 DEG F  
BOT PATTERN FACTOR = .0829  
OUTER ANNULUS TCG AVERAGE STD DEV  
1 1699 9  
4 1708 28  
7 1562 31  
10 1532 9  
13 1580 9  
16 1763 9  
19 1740 14  
22 1709 11  
25 1682 11  
28 1689 9  
31 1747 12  
34 1631 29  
37 1648 9  
40 1611 10  
43 1724 12

\* EXHAUST CHEMISTRY \*

\* EXHAUST CHEMISTRY \*

CO.. .040 % CO2..4.15 % O2..15.2 % UBN..4.3 PPM (PROPANE)  
NO.. 49.8 PPM NOX.. 55.5 PPM NO2.. 5.7 PPM (NOX-NO)  
SMOKE NUMBER: 26.6

CO.. .080 % CO2..4.40 % O2..14.7 % UBN..38.9 PPM (PROPANE)  
NO.. 29.5 PPM NOX.. 26.4 PPM NO2.. 5.9 PPM (NOX-NO)  
SMOKE NUMBER: 8.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5018  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .019009  
REMARKS:

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 98.0021  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021135  
REMARKS:

Figure 45 - Test Report of Experiment No. 38

Figure 44 - Test Report of Experiment No. 37

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES

U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 2:51  
COMBUSTION SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

	AVERAGE	STD. DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	65.56	2.24	65.40	65.60
INLET AIR TEMPERATURE, DEG F	527.36	2.89	524.00	526.05
AIR FLOW RATE, LBS/SEC	2.305	.019	2.280	2.315
FUEL FLOW RATE, LBS/MIN	3.165	.026	3.150	3.190
FUEL-AIR RATIO	.02289	.00026	.02280	.02296
AIR FLOW LOADING FACTOR	1.1047	.0089	1.0940	1.1084

FUEL PRESSURE= 343  
FUEL TEMPERATURE=130.6 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT F/C=1685.5 DEG F  
BOT HOT SPOT: TCR 8 = 1777 DEG F  
BOT PATTERN FACTOR = .0794

	TCR	AVERAGE	STD DEV
OUTER ANNULUS	1	1678	11
	4	0	103
	7	0	75
	10	1613	12
	13	1577	11
CENTER ANNULUS	2	1765	11
	5	1749	12
	8	1777	14
	11	1697	14
	14	1691	10
INNER ANNULUS	3	1718	12
	6	1614	32
	9	1663	14
	12	1639	12
	15	1727	12

\* EXHAUST CHEMISTRY \*

CO... .056 % CO2...4.20 % O2...14.9 % UHM...14.2 PPM (PROPANE)  
NO... 35.8 PPM NOX... 41.5 PPM NO2... 5.7 PPM (NOX-NO)  
SMOKE NUMBER: 13.2

COMBUSTION EFFICIENCY: CALCULATED FROM EXHAUST CHEMISTRY: 98.2444  
FUEL-AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .02036  
REMARKS:

Figure 46 - Test Report of Experiment No. 39

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES

U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 3:15  
COMBUSTION SYSTEM: T-63 POWER POINT: 100%  
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

	AVERAGE	STD. DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	65.91	.25	65.40	66.10
INLET AIR TEMPERATURE, DEG F	527.61	3.18	524.00	525.41
AIR FLOW RATE, LBS/SEC	2.304	.017	2.280	2.315
FUEL FLOW RATE, LBS/MIN	3.522	.030	3.560	3.523
FUEL-AIR RATIO	.02549	.00031	.02570	.02536
AIR FLOW LOADING FACTOR	1.0984	.0097	1.0940	1.0992

FUEL PRESSURE= 378  
FUEL TEMPERATURE=123.3 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT F/C=1550.9 DEG F  
BOT HOT SPOT: TCR 8 = 1726 DEG F  
BOT PATTERN FACTOR = .0672

	TCR	AVERAGE	STD DEV
OUTER ANNULUS	1	1639	12
	4	0	132
	7	0	135
	10	1525	11
	13	1542	10
CENTER ANNULUS	2	1724	12
	5	1711	12
	8	1726	10
	11	1664	13
	14	1656	10
INNER ANNULUS	3	1657	14
	6	0	113
	9	1630	10
	12	1602	16
	15	1694	8

\* EXHAUST CHEMISTRY \*

CO... .069 % CO2...4.15 % O2...14.9 % UHM...28.6 PPM (PROPANE)  
NO... 26.0 PPM NOX... 33.0 PPM NO2... 7.0 PPM (NOX-NO)  
SMOKE NUMBER: 9.3

COMBUSTION EFFICIENCY: CALCULATED FROM EXHAUST CHEMISTRY: 99.0190  
FUEL-AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .020239  
REMARKS:

NAEC-92-114

Figure 47 - Test Report of Experiment No. 40

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 8-21-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR

TIME: 3:51  
POWER POINT: 75%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 56.24  
INLET AIR TEMPERATURE, DEG F 473.84  
AIR FLOW RATE, LBS/SEC 2.098  
AIR FLOW RATE, LBS/MIN 2.183  
FUEL/AIR RATIO .01678  
AIR FLOW LOADING FACTOR 1.1813  
LAST SCAN 57.40  
477.27  
2.051  
2.098  
2.180  
2.098  
2.180  
1.0994

FUEL PRESSURE= 240  
FUEL TEMPERATURE=154.9 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1483.2 DEG F

BOT HOT SPOT: TCR 2 = 1602 DEG F

BOT PATTERN FACTOR = .1174

OUTER ANNULUS TCR AVERAGE STD DEV

1 1510 15

4 1474 23

7 1326 98

10 1367 17

13 1582 15

2 1511 12

5 1565 14

8 1438 15

11 1584 11

14 1596 14

3 1458 37

6 1462 14

9 1423 16

12 1538 12

\* EXHAUST CHEMISTRY \*

CO.. .867 % CO2..3.58 % O2..15.9 % URM..34.7 PPM (PROPANE)  
NO.. 29.4 PPM NOX.. 35.8 PPM NO2.. 9.6 PPM (NOX-NO)  
SNAKE NUMBER: 24.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 98.8143  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .017095  
REMARKS:

Figure 48 - Test Report of Experiment No. 41

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTION FACILITY  
STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 8-21-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR EMULSIFIED WITH 15% WATER

TIME: 4:13  
POWER POINT: 75%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 56.84  
INLET AIR TEMPERATURE, DEG F 474.82  
AIR FLOW RATE, LBS/SEC 2.098  
AIR FLOW RATE, LBS/MIN 2.422  
FUEL/AIR RATIO .00333  
AIR FLOW LOADING FACTOR 1.1285  
LAST SCAN 56.88  
473.38  
2.093  
2.398  
2.418  
2.0197  
1.1278

FUEL PRESSURE= 253  
FUEL TEMPERATURE=141.8 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1432.7 DEG F

BOT HOT SPOT: TCR 2 = 1574 DEG F

BOT PATTERN FACTOR = .1472

OUTER ANNULUS TCR AVERAGE STD DEV

1 1502 16

4 1254 79

7 1335 11

10 1376 12

13 1574 16

2 1493 16

5 1529 17

8 1435 15

11 1485 15

14 1487 17

3 1316 99

6 1374 19

9 1393 19

12 1516 14

\* EXHAUST CHEMISTRY \*

CO.. .899 % CO2..3.48 % O2..16.0 % URM..80.0 PPM (PROPANE)  
NO.. 23.0 PPM NOX.. 29.3 PPM NO2.. 6.3 PPM (NOX-NO)  
SNAKE NUMBER: 12.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 97.9108  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .016862  
REMARKS:

Figure 49 - Test Report of Experiment No. 42

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 8-22-78  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR EMULSIFIED WITH 30% WATER  
TIME: 9:10  
POWER POINT: 75%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 57.33  
INLET AIR TEMPERATURE, DEG F 471.98  
AIR FLOW RATE, LBS/SEC 2.069  
FUEL FLOW RATE, LBS/MIN 2.729  
FUEL/AIR RATIO .02177  
AIR FLOW LOADING FACTOR 1.1127  
DESIRE 57.40  
57.68  
473.63  
2.110  
2.730  
0.020  
0.02160  
1.1230  
LAST SCAN 57.68  
57.68  
473.63  
2.167  
2.739  
0.02182  
1.1178

FUEL PRESSURE= 285  
FUEL TEMPERATURE=124.1 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1465.7 DEG F  
BOT HOT SPOT: TCM 3 = 1622 DEG F  
BOT PATTERN FACTOR = .1578

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1538	12	15
4	1508	15	25
7	0	8	8
10	1333	8	8
13	1355	12	23
16	1618	10	11
19	1472	9	9
22	1516	12	12
25	1410	11	11
28	1495	12	12
31	1622	12	28
34	1388	16	16
37	1361	16	16
40	1364	16	16
43	1541	16	16

\* EXHAUST CHEMISTRY \*

CO... 104 % CO2... 3.60 % O2... 16.1 % UHM... 101.3 PPM (PROPANE)  
H2O... 20.5 PPM NOX... 25.0 PPM NO2... 4.5 PPM (NOX-HO)  
SMOKE NUMBER: 7.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 97.0007  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .017338  
REMARKS:

Figure 50 - Test Report of Experiment No. 43

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 8-22-78  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR  
TIME: 9:48  
POWER POINT: 55%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 59.92  
INLET AIR TEMPERATURE, DEG F 428.15  
AIR FLOW RATE, LBS/SEC 1.931  
FUEL FLOW RATE, LBS/MIN 1.692  
FUEL/AIR RATIO .01468  
AIR FLOW LOADING FACTOR 1.1304  
DESIRE 59.70  
430.00  
1.930  
1.690  
0.01450  
1.1372  
LAST SCAN 59.68  
426.97  
1.932  
1.668  
0.01432  
1.1372

FUEL PRESSURE= 210  
FUEL TEMPERATURE=137.1 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1275.9 DEG F  
BOT HOT SPOT: TCM 2 = 1482 DEG F  
BOT PATTERN FACTOR = .2433

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1419	12	13
4	1316	13	13
7	0	8	8
10	1120	8	8
13	1230	12	12
16	1482	12	64
19	1208	21	21
22	1205	7	7
25	1217	9	9
28	1349	13	13
31	1461	27	27
34	1165	7	7
37	1201	33	33
40	1089	10	10
43	1399	10	10

\* EXHAUST CHEMISTRY \*

CO... .084 % CO2... 3.87 % O2... 16.6 % UHM... 75.7 PPM (PROPANE)  
H2O... 22.5 PPM NOX... 30.3 PPM NO2... 7.8 PPM (NOX-HO)  
SMOKE NUMBER: 19.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.0093  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .015132  
REMARKS:

NAEC-92-114

Figure 51 - Test Report of Experiment No. 44

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/22/76 TIME: 10:22  
COMBUSTOR SYSTEM: T-63 POWER POINT: 55%  
TEST FUEL: JPS-HSR EMULSIFIED WITH 15% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 50.82 DESIRED 50.70 LAST SCAN 50.80  
INLET AIR TEMPERATURE, DEG F 427.86 1.17 438.00 426.32  
AIR FLOW RATE, LBS/SEC 1.946 1.018 1.950 1.943  
FUEL FLOW RATE, LBS/MIN 1.933 .928 1.943 1.911  
FUEL/AIR RATIO .0156 .00819 .01678 .01538  
AIR FLOW LOADING FACTOR 1.1486 .0061 1.1478 1.1399

FUEL PRESSURE= 222  
FUEL TEMPERATURE=134.9 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1233.3 DEG F  
BOT HOT SPOT: TCM 2 = 1449 DEG F  
BOT PATTERN FACTOR = .2674  
TC# AVERAGE STD DEV  
OUTER ANNULUS 1 1397 11  
2 1231 67  
3 1109 4  
4 1109 11  
5 1189 8  
6 1449 11  
7 1065 62  
8 1154 16  
9 1187 11  
10 1314 10  
11 1438 13  
12 1109 40  
13 1221 7  
14 1043 32  
15 1367 12

\* EXHAUST CHEMISTRY \*

CO.. 109 % CO2.. 3.00 % O2.. 16.5 % URM. 138.0 PPM (PPOFANE)  
NO.. 18.5 PPM NOX.. 23.8 PPM NO2.. 5.3 PPM (NOX-HO)  
SMOKE NUMBER: 9.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.8638  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .015154  
REMARKS:

Figure 52 - Test Report of Experiment No. 45

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY  
\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/22/76 TIME: 10:44  
COMBUSTOR SYSTEM: T-63 POWER POINT: 55%  
TEST FUEL: JPS-HSR EMULSIFIED WITH 38% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 51.06 DESIRED 50.70 LAST SCAN 51.30  
INLET AIR TEMPERATURE, DEG F 429.57 1.19 438.00 423.70  
AIR FLOW RATE, LBS/SEC 1.942 .012 1.950 1.943  
FUEL FLOW RATE, LBS/MIN 2.178 .019 2.198 2.165  
FUEL/AIR RATIO .00828 .00028 .01658 .01558  
AIR FLOW LOADING FACTOR 1.1344 .0072 1.1478 1.1288

FUEL PRESSURE= 235  
FUEL TEMPERATURE=129.3 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1248.0 DEG F  
BOT HOT SPOT: TCM 2 = 1449 DEG F  
BOT PATTERN FACTOR = .2455  
TC# AVERAGE STD DEV  
OUTER ANNULUS 1 1398 12  
2 1285 20  
3 1114 7  
4 1114 11  
5 1190 17  
6 1449 12  
7 1079 77  
8 1208 15  
9 1199 9  
10 1319 15  
11 1397 39  
12 1103 9  
13 1237 9  
14 1132 18  
15 1363 10

\* EXHAUST CHEMISTRY \*

CO.. 121 % CO2.. 3.05 % O2.. 16.7 % URM. 194.3 PPM (PPOFANE)  
NO.. 15.3 PPM NOX.. 18.8 PPM NO2.. 3.5 PPM (NOX-HO)  
SMOKE NUMBER: 5.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.4240  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .018296  
REMARKS:

Figure 53 - Test Report of Experiment No. 46

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/23/76 TIME: 9:38  
COMBUSTOR SYSTEM: T-63 POWER POINT: 40%  
TEST FUEL: JPS-HBR EMULSIFIED WITH 2% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 45.75 AVERAGE STD. DEV. 43.40 DESIRED LAST SCAM 43.40  
INLET AIR TEMPERATURE, DEG F 401.16 1.19 397.00 400.85  
AIR FLOW RATE, LBS/SEC 1.816 .023 1.798 1.801  
FUEL FLOW RATE, LBS/HIN 1.423 .023 1.400 1.414  
FUEL/AIR RATIO .01305 -.00024 .01310 .01309  
AIR FLOW LOADING FACTOR 1.1661 .0135 1.1630 1.1638

FUEL PRESSURE= 120  
FUEL TEMPERATURE=133.6 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1241.3 DEG F  
BOT HOT SPOT: TCR 2 = 1302 DEG F  
BOT PATTERN FACTOR = .1676

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1285	14	14
4	1236	18	18
7	0	46	46
10	0	17	17
13	1100	9	9
14	1302	14	14
15	1231	14	14
16	1200	10	10
17	1111	12	12
18	1111	11	11
19	1230	11	11
20	1300	17	17
21	1242	25	25
22	1217	19	19
23	1136	12	12
24	1291	12	12

\* EXHAUST CHEMISTRY \*

CO... .091 % CO2...2.76 % O2...17.2 % UHM... 112.3 PPM (PROPANE)  
NO... 15.4 PPM NOX... 21.2 PPM 102... 5.6 PPM (NOX-NO)  
SMOKE NUMBER: 13.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 97.304  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .01307  
REMARKS:

Figure 54 - Test Report of Experiment No. 47

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/76 TIME: 10:7  
COMBUSTOR SYSTEM: T-63 POWER POINT: 40%  
TEST FUEL: JPS-HBR EMULSIFIED WITH 15% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 44.19 AVERAGE STD. DEV. 45.10 DESIRED LAST SCAM 45.10  
INLET AIR TEMPERATURE, DEG F 398.12 1.17 397.00 397.62  
AIR FLOW RATE, LBS/SEC 1.777 .025 1.758 1.758  
FUEL FLOW RATE, LBS/HIN 1.595 .021 1.510 1.509  
FUEL/AIR RATIO .01497 .00017 .01510 .01517  
AIR FLOW LOADING FACTOR 1.1779 .0129 1.1630 1.1702

FUEL PRESSURE= 200  
FUEL TEMPERATURE=134.9 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1221.6 DEG F  
BOT HOT SPOT: TCR 2 = 1363 DEG F  
BOT PATTERN FACTOR = .1721

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	1266	16	16
4	1215	11	11
7	1176	8	8
10	1003	11	11
13	1363	16	16
16	1200	10	10
19	1206	11	11
22	1090	11	11
25	1220	10	10
28	1357	15	15
31	1236	10	10
34	1209	9	9
37	1116	8	8
40	1270	12	12

\* EXHAUST CHEMISTRY \*

CO... .120 % CO2...2.76 % O2...17.0 % UHM... 200.0 PPM (PROPANE)  
NO... 12.0 PPM NOX... 16.0 PPM 102... 4.0 PPM (NOX-NO)  
SMOKE NUMBER: 5.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.0315  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .01401  
REMARKS:

Figure 55 - Test Report of Experiment No. 48

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 5-28-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR EMULSIFIED WITH 30% WATER

TIME: 10:38  
POWER POINT: 40%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

INLET AIR PRESSURE, PSIA	AVERAGE STD. DEV.	DESIRED	LAST SCAN
45.82	.41	1.16	46.30
INLET AIR TEMPERATURE, DEG F	398.70	1.20	399.13
AIR FLOW RATE, LBS/SEC	1.821	.026	1.788
FUEL FLOW RATE, LBS/MIN	1.840	.018	1.843
FUEL/AIR RATIO	.01685	.00033	.01718
AIR FLOW LOADING FACTOR	1.1643	.0120	1.1317

FUEL PRESSURE= 212  
FUEL TEMPERATURE=128.9 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1190.7 DEG F  
BOT HOT SPOT: TCG 2 = 1331 DEG F  
BOT PATTERN FACTOR = .1770

OUTER ANNULUS	TC#	AVERAGE	STD DEV
1	1241	18	18
4	1199	16	16
7	1104	28	28
10	1072	11	11
13	1072	12	12
16	1331	18	18
19	1181	13	13
22	1241	13	13
25	1079	15	15
28	1191	13	13
31	1327	17	17
34	1190	14	14
37	1171	13	13
40	1094	13	13
43	1241	15	15

\* EXHAUST CHEMISTRY \*

CO.. .136 % CO2..2.70 % O2..17.0 % URM. 270.3 PPM (PROPANE)  
NO.. 10.2 PPM NOX.. 12.7 PPM NO2.. 2.5 PPM (NOX-NO)  
SMOKE NUMBER: 3.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 95.0206  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .013050  
REMARKS:

Figure 56 - Test Report of Experiment No. 49

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-28-76  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR

TIME: 11:13  
POWER POINT: 25%

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*

INLET AIR PRESSURE, PSIA	AVERAGE STD. DEV.	DESIRED	LAST SCAN
39.91	.15	38.00	39.70
INLET AIR TEMPERATURE, DEG F	355.23	.68	353.00
AIR FLOW RATE, LBS/SEC	1.566	.009	1.560
FUEL FLOW RATE, LBS/MIN	1.147	.012	1.135
FUEL/AIR RATIO	.01221	.00014	.01210
AIR FLOW LOADING FACTOR	1.1462	.0002	1.1450

FUEL PRESSURE= 175  
FUEL TEMPERATURE=144.8 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG=1133.2 DEG F  
BOT HOT SPOT: TCG 3 = 1264 DEG F  
BOT PATTERN FACTOR = .1695

OUTER ANNULUS	TC#	AVERAGE	STD DEV
1	1162	10	10
4	1150	8	8
7	1110	6	6
10	1017	7	7
13	1247	10	10
16	1132	7	7
19	1177	10	10
22	1002	9	9
25	1120	7	7
28	1264	12	12
31	1158	7	7
34	1124	6	6
37	1028	7	7
40	1172	8	8

\* EXHAUST CHEMISTRY \*

CO.. .114 % CO2..2.52 % O2..17.4 % URM. 163.7 PPM (PROPANE)  
NO.. 11.0 PPM NOX.. 15.3 PPM NO2.. 4.3 PPM (NOX-NO)  
SMOKE NUMBER: 7.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.1630  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .012763  
REMARKS:

Figure 57 - Test Report of Experiment No. 50

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 3/28/76 TIME: 11:38  
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%  
TEST FUEL: JP5-NOR EMULSIFIED WITH 15% WATER

\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*  
INLET AIR PRESSURE, PSIA 39.09 DESIRED 38.00 LAST SCAN 39.20  
INLET AIR TEMPERATURE, DEG F 356.59 DESIRED 353.00 357.03  
AIR FLOW RATE, LBS/SEC 1.567 DESIRED 1.568 1.568  
FUEL FLOW RATE, LBS/MIN 1.292 DESIRED 1.290 1.271  
FUEL/AIR RATIO .01374 DESIRED .01390 0.1358  
AIR FLOW LOADING FACTOR 1.1456 DESIRED 1.1450 1.1377

FUEL PRESSURE= 185  
FUEL TEMPERATURE=142.3 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT H/C=1116.0 DEG F  
BOT HOT SPOT: TCO 3 = 1240 DEG F  
BOT PATTERN FACTOR = .1637

OUTER ANNULUS	TCO	AVERAGE	STD DEV
1	1155	14	
4	1118	11	
7	1090	10	
10	9	8	
13	1007	9	
16	1230	14	
19	1106	10	
22	1159	13	
25	966	11	
28	1167	11	
31	1240	15	
34	1136	11	
37	1167	11	
40	1014	10	
43	1161	11	

\* EXHAUST CHEMISTRY \*

CO... .135 % CO2...2.30 % O2...17.5 % UHM...26.7 PPM (PROPANE)  
NO... 9.3 PPM NOX... 12.3 PPM NO2... 3.0 PPM (NOX-NO)  
SMOKE NUMBER: 3.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.4994  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .013808  
REMARKS:

Figure 58 - Test Report of Experiment No. 51

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*\*  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 3/28/76 TIME: 12:10  
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%  
TEST FUEL: JP5-NOR EMULSIFIED WITH 30% WATER

\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*  
INLET AIR PRESSURE, PSIA 39.24 DESIRED 38.00 LAST SCAN 39.20  
INLET AIR TEMPERATURE, DEG F 356.91 DESIRED 353.00 355.93  
AIR FLOW RATE, LBS/SEC 1.563 DESIRED 1.568 1.564  
FUEL FLOW RATE, LBS/MIN 1.443 DESIRED 1.460 1.434  
FUEL/AIR RATIO .01539 DESIRED .01570 0.1528  
AIR FLOW LOADING FACTOR 1.1384 DESIRED 1.1450 1.1400

FUEL PRESSURE= 185  
FUEL TEMPERATURE=139.7 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT H/C=1082.2 DEG F  
BOT HOT SPOT: TCO 3 = 1207 DEG F  
BOT PATTERN FACTOR = .1716

OUTER ANNULUS	TCO	AVERAGE	STD DEV
1	1122	11	
4	1082	7	
7	1053	6	
10	8	5	
13	986	6	
16	1197	11	
19	1066	6	
22	1101	8	
25	975	7	
28	1079	7	
31	1207	13	
34	1091	6	
37	1048	6	
40	937	6	
43	1128	7	

\* EXHAUST CHEMISTRY \*

CO... .148 % CO2...2.35 % O2...17.5 % UHM...374.7 PPM (PROPANE)  
NO... 7.5 PPM NOX... 9.5 PPM NO2... 2.0 PPM (NOX-NO)  
SMOKE NUMBER: 2.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 93.0210  
FUEL/AIR RATIO: CALCULATED FROM EXHAUST CHEMISTRY: .012406  
REMARKS:

Figure 59 - Test Report of Experiment No. 52

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*  
U.S. NAVY AIR ENGINEERING CENTER

Date: 6-28-76 TIME: 11:31  
COMBUSTOR SYSTEM: T-63 POWER POINT: 10%  
TEST FUEL: JP-5-HBR EMULSIFIED WITH 15% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 32.68 DESIRED 31.50  
INLET AIR TEMPERATURE, DEG F 318.33 300.00  
AIR FLOW RATE, LBS/SEC 1.348 1.326  
FUEL FLOW RATE, LBS/MIN 1.005 1.000  
FUEL/AIR RATIO 0.01243 0.01250  
AIR FLOW LOADING FACTOR 1.1508 1.1479

FUEL PRESSURE= 160  
FUEL TEMPERATURE= 158.2 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOI AVG= 978.3 DEG F  
BOI HOT SPOT: TCR 3 = 1102 DEG F  
BOI PATTERN FACTOR = .1888  
TCR AVERAGE STD DEV  
OUTER ANNULUS 1 399 32  
2 993 32  
3 141 29  
4 10 21  
5 896 24  
6 1000 32  
7 969 31  
8 986 33  
9 989 24  
10 974 30  
11 102 37  
12 962 33  
13 965 31  
14 904 25  
15 1015 33

\* EXHAUST CHEMISTRY \*

CO... 150 % CO2... 2.00 % O2... 16.1 % U.S.H. 437.7' PPM (PROPANE)  
NO... 5.3 PPM NOX... 8.2 PPM NO2... 2.9 PPM (NOX-NO)  
SMOKE NUMBER: 2.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 91.1448  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .010048  
REMARKS:

Figure 61 - Test Report of Experiment No. 54

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

\*\*\* STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES \*\*  
U.S. NAVY AIR ENGINEERING CENTER

Date: 6-28-76 TIME: 12:59  
COMBUSTOR SYSTEM: T-63 POWER POINT: 10%  
TEST FUEL: JP-5-HBR

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 33.46 DESIRED 31.50  
INLET AIR TEMPERATURE, DEG F 313.12 300.00  
AIR FLOW RATE, LBS/SEC 1.376 1.326  
FUEL FLOW RATE, LBS/MIN 1.071 1.000  
FUEL/AIR RATIO 0.01055 0.01000  
AIR FLOW LOADING FACTOR 1.1431 1.1406

FUEL PRESSURE= 162  
FUEL TEMPERATURE= 158.2 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOI AVG= 969.6 DEG F  
BOI HOT SPOT: TCR 3 = 1087 DEG F  
BOI PATTERN FACTOR = .1782  
TCR AVERAGE STD DEV  
OUTER ANNULUS 1 977 10  
2 992 11  
3 941 11  
4 10 9  
5 890 10  
6 1056 10  
7 971 11  
8 979 11  
9 882 10  
10 961 11  
11 1007 11  
12 983 13  
13 961 11  
14 890 10  
15 997 12

\* EXHAUST CHEMISTRY \*

CO... 124 % CO2... 2.05 % O2... 16.0 % U.S.H. 240.7 PPM (PROPANE)  
NO... 6.0 PPM NOX... 9.5 PPM NO2... 2.7 PPM (NOX-NO)  
SMOKE NUMBER: 0.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.0701  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .010740  
REMARKS:

Figure 60 - Test Report of Experiment No. 53

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY  
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES  
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/75  
COMBUSTOR SYSTEM: T-63  
TEST FUEL: JPS-HBR EMULSIFIED WITH 30% WATER  
TIME: 1:57  
POWER POINT: 10%  
30% WATER

\*\*\*\*\* EXPERIMENTAL TEST CONDITIONS \*\*\*\*\*  
INLET AIR PRESSURE, PSIA 32.68  
INLET AIR TEMPERATURE, DEG F 318.58  
AIR FLOW RATE, LBS/SEC. 1.346  
FUEL FLOW RATE, LBS/AIR 1.113  
FUEL/AIR RATIO .01378  
AIR FLOW LOADING FACTOR 1.1519  
AVERAGE STD. DEV. DESIRED LAST SCAN  
27 31.50 32.20  
32 300.00 317.53  
33 1.320 1.340  
34 1.127 1.104  
35 .01420 .01373  
36 .0122 1.1500 1.1607

FUEL PRESSURE= 170  
FUEL TEMPERATURE=150.9 DEG F

\* BURNER OUTLET TEMPERATURE SURVEY \*

BOT AVG= 938.3 DEG F  
BOT HOT SPOT: TCR 3 = 1049 DEG F  
BOT PATTERN FACTOR = .1790

OUTER ANNULUS	TCR	AVERAGE	STD DEV
1	972	12	12
4	937	12	12
7	892	10	10
10	870	9	9
13	870	12	12
16	1041	11	11
19	916	13	13
22	932	10	10
25	867	11	11
28	942	15	15
31	1049	11	11
34	929	11	11
37	930	10	10
40	878	11	11
43	900	11	11

\* EXHAUST CHEMISTRY \*

CO.. .160 % CO2..1.95 % O2..10.1 % UGN. 511.3 PPM (PROPANE)  
NO.. 4.4 PPM NOX.. 6.6 PPM NO2.. 2.2 PPM (NOX-NO)  
SMOKE NUMBER: 1.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 89.0032  
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .010016  
REMARKS:

Figure 62 - Test Report of Experiment No. 55

Exp. #	$\Delta P$	SN
○ 1	(neat fuel)	24.4
□ 2	2600	16.9
◇ 3	1600	17.0
△ 4	200	17.3

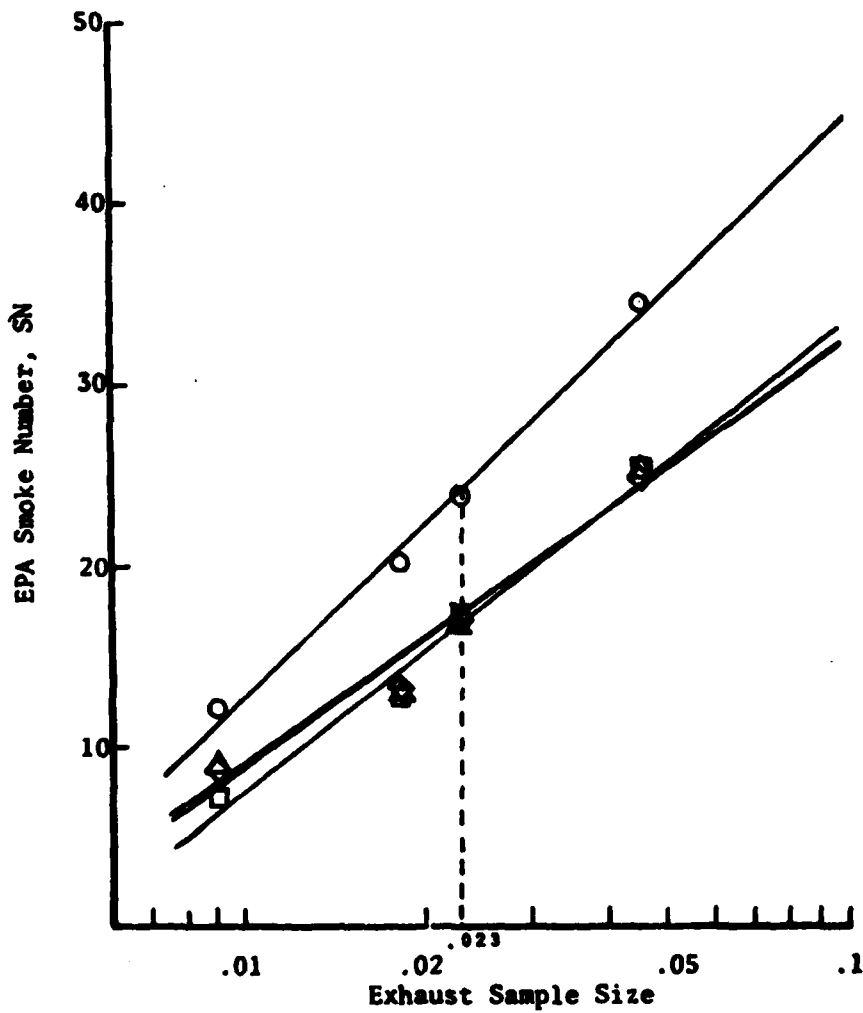


Figure 63 - Smoke Number Evaluations for Experiments 1, 2, 3, and 4 Showing the Effect of Homogenizer Pressure Drop on Smoke Reduction

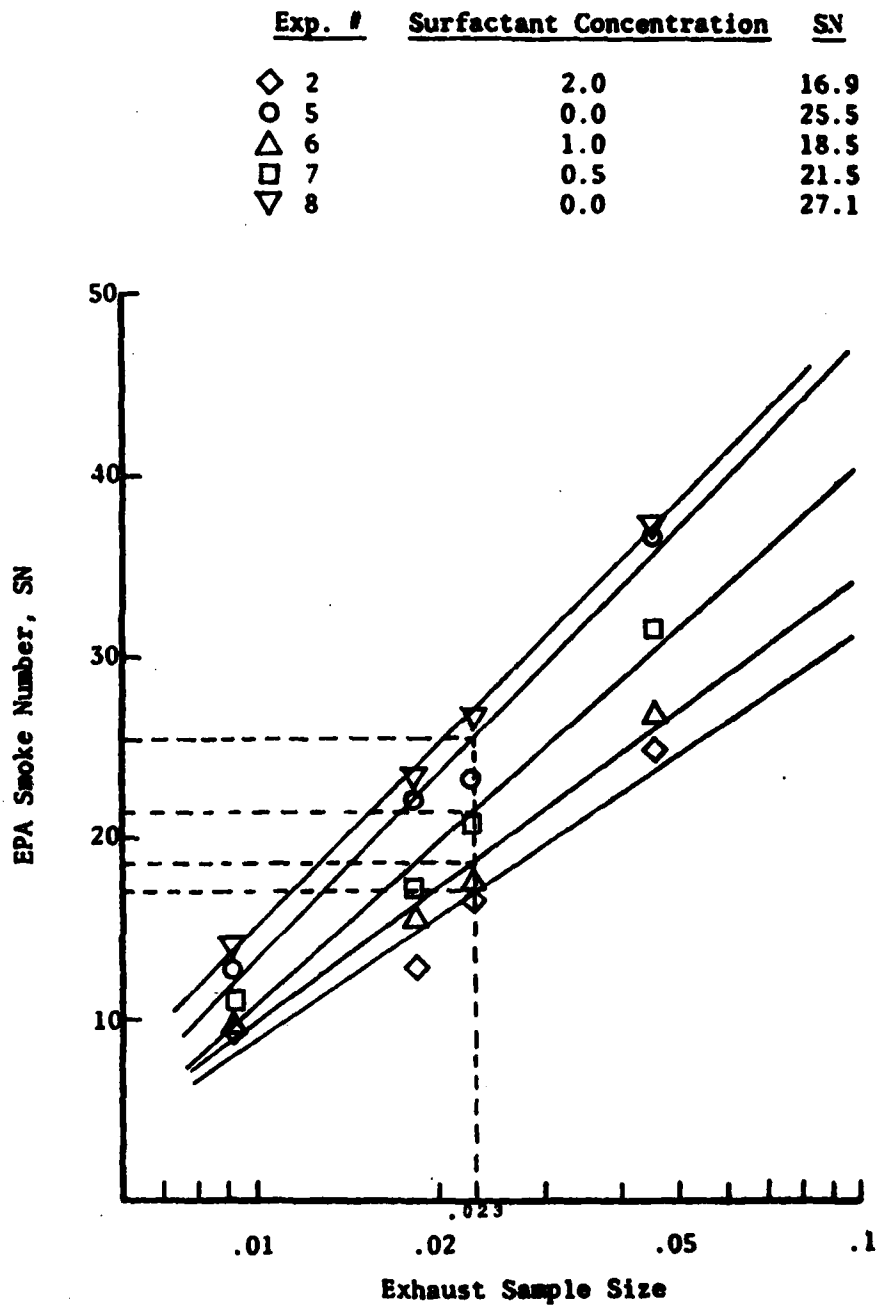


Figure 64 - Smoke Number Evaluations for Experiments 2, 5, 6, 7, and 8 Showing the Effect of Surfactant Concentration for an Emulsion of 10% Water

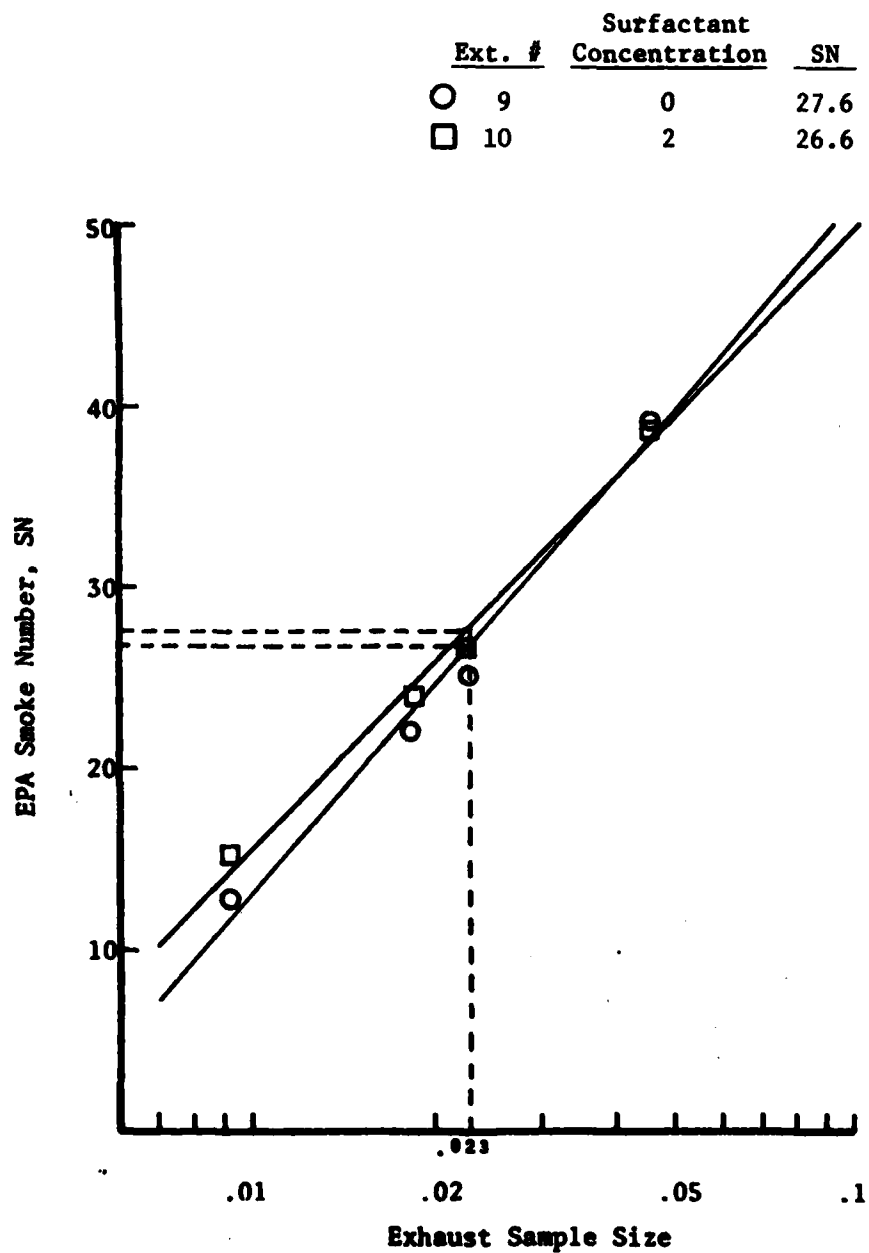


Figure 65 - Smoke Number Evaluations for Experiments 9 and 10  
Showing the Effect of Just the Surfactant on Smoke  
Level

	<u>Exp. #</u>	<u>Surfactant Concentration</u>	<u>SN</u>
○	11	0.0	27.2
□	13	2.0	21.4
△	14	1.0	23.0
◇	15	0.5	24.0

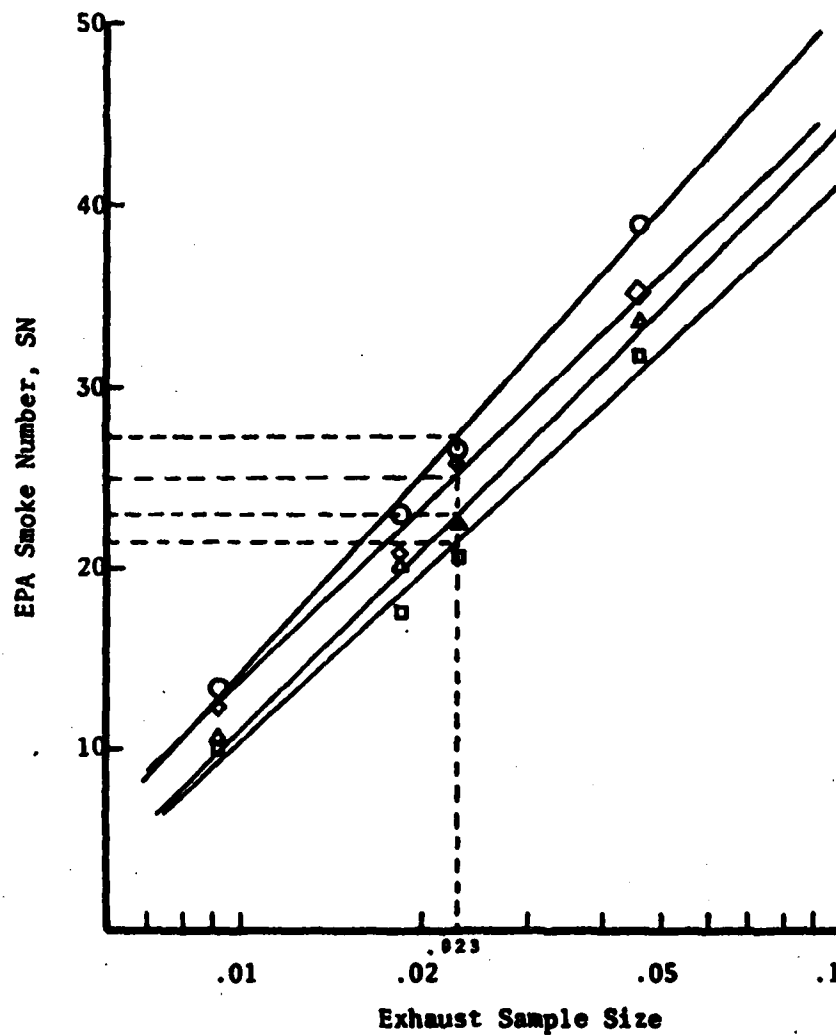


Figure 66 - Smoke Number Evaluations for Experiments 11, 13, 14, and 15 Showing the Effect of Surfactant Concentration for an Emulsion of 5% Water

Exp. #	Fuel System	SN
● 16	JP5-HA	33.6
○ 17	JP5-HA emulsified w/10% water	23.8
■ 18	JP5-HBR	25.0
□ 19	JP5-HBR emulsified w/10% water	15.4

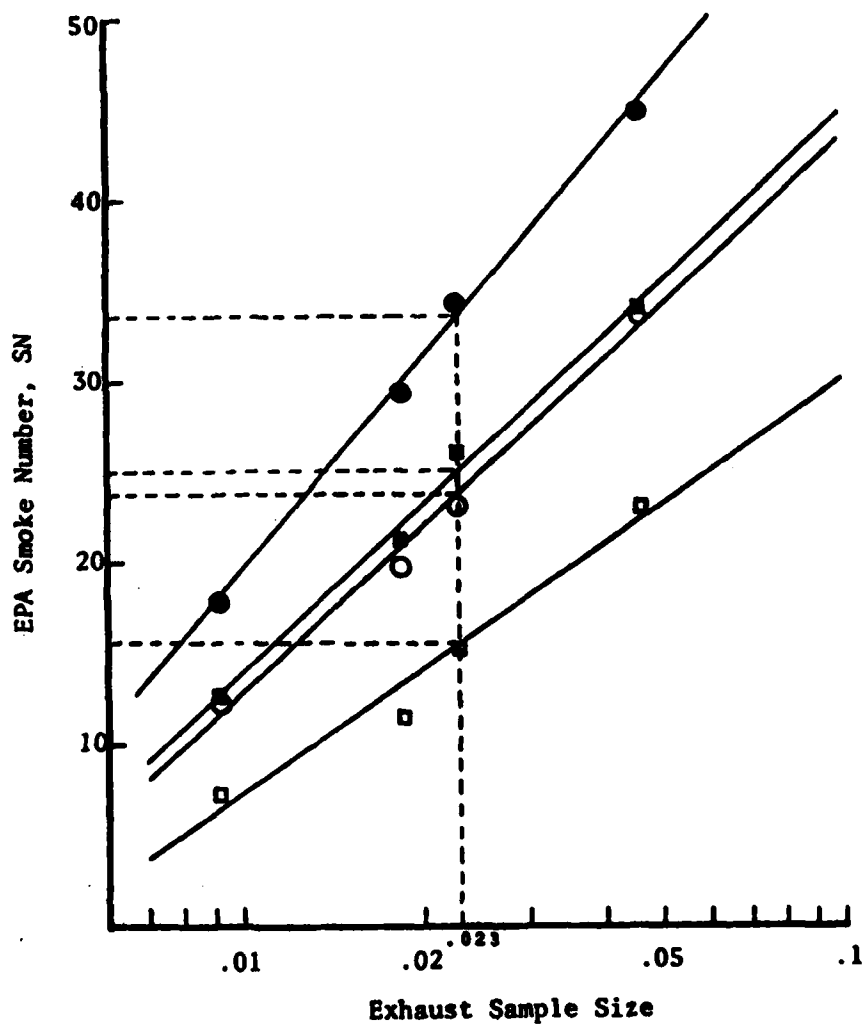


Figure 67 - Smoke Number Evaluations for Experiments 16, 17, 18, and 19 Showing Sensitivity of Concept to Fuel Type

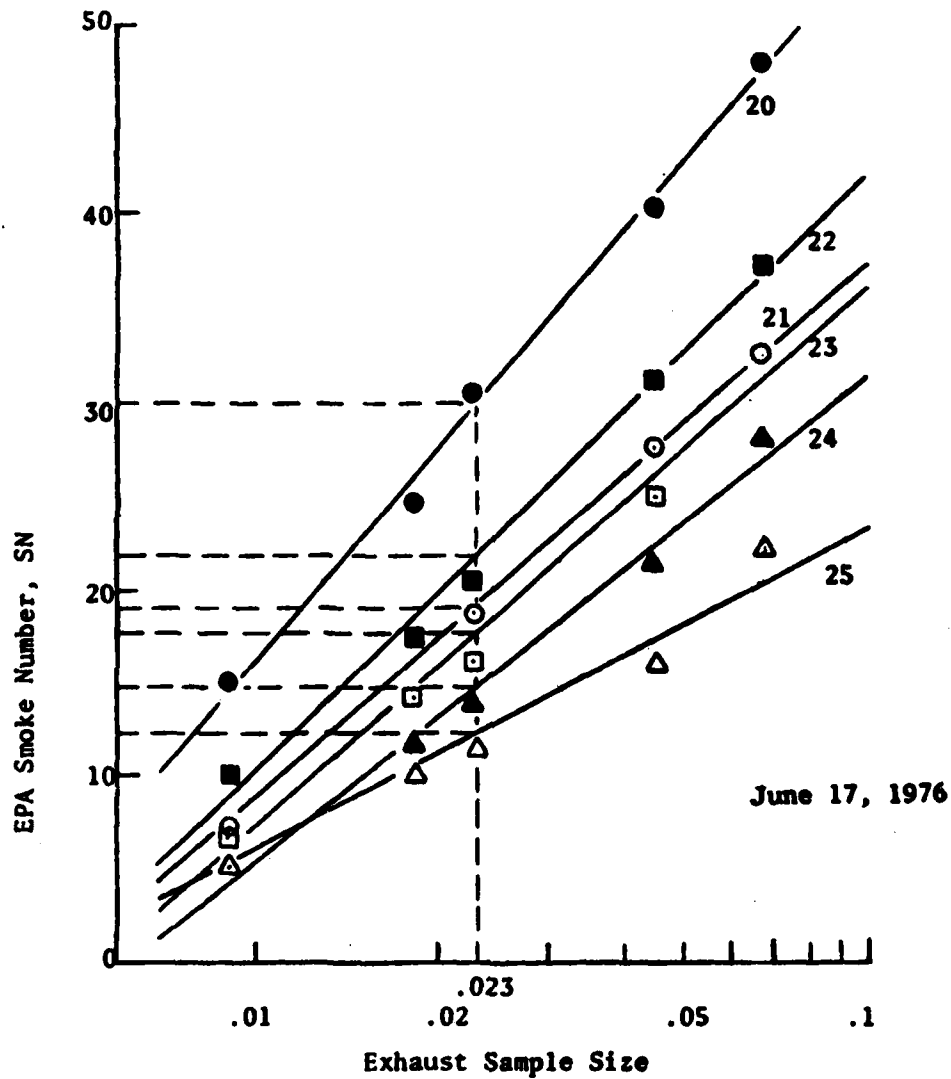


Figure 68 - Smoke Number Evaluations for Experiments 20, 21, 22, 23, 24, and 25

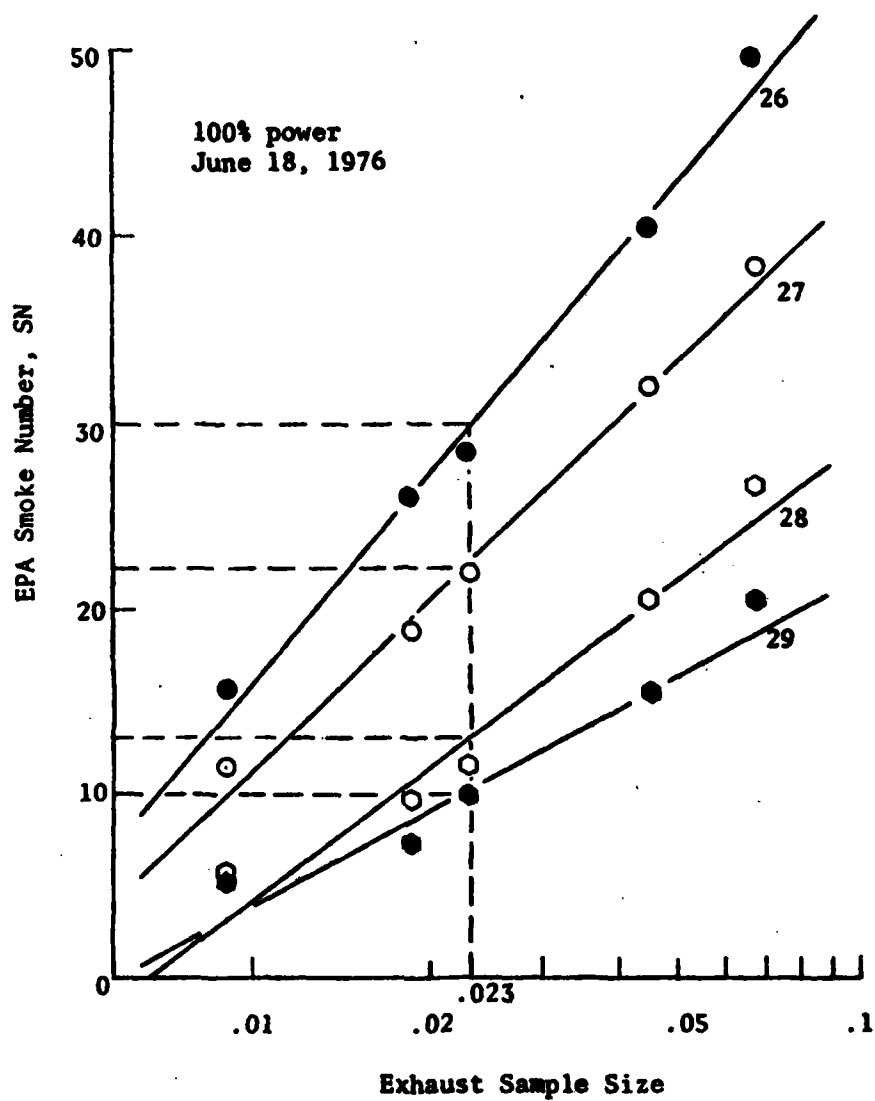


Figure 69 - Smoke Number Evaluations for Experiments 26, 27, 28, and 29

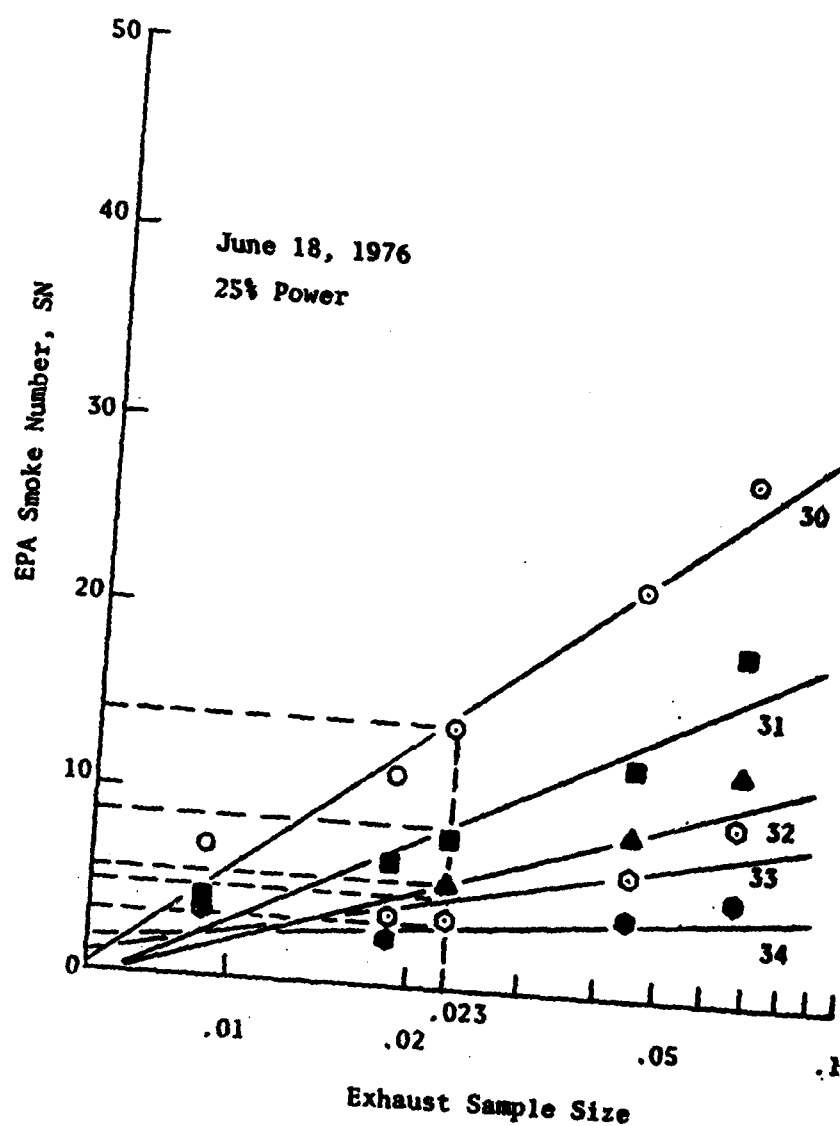


Figure 70 - Smoke Number Evaluations for Experiments 30, 31, 32, 33, and 34

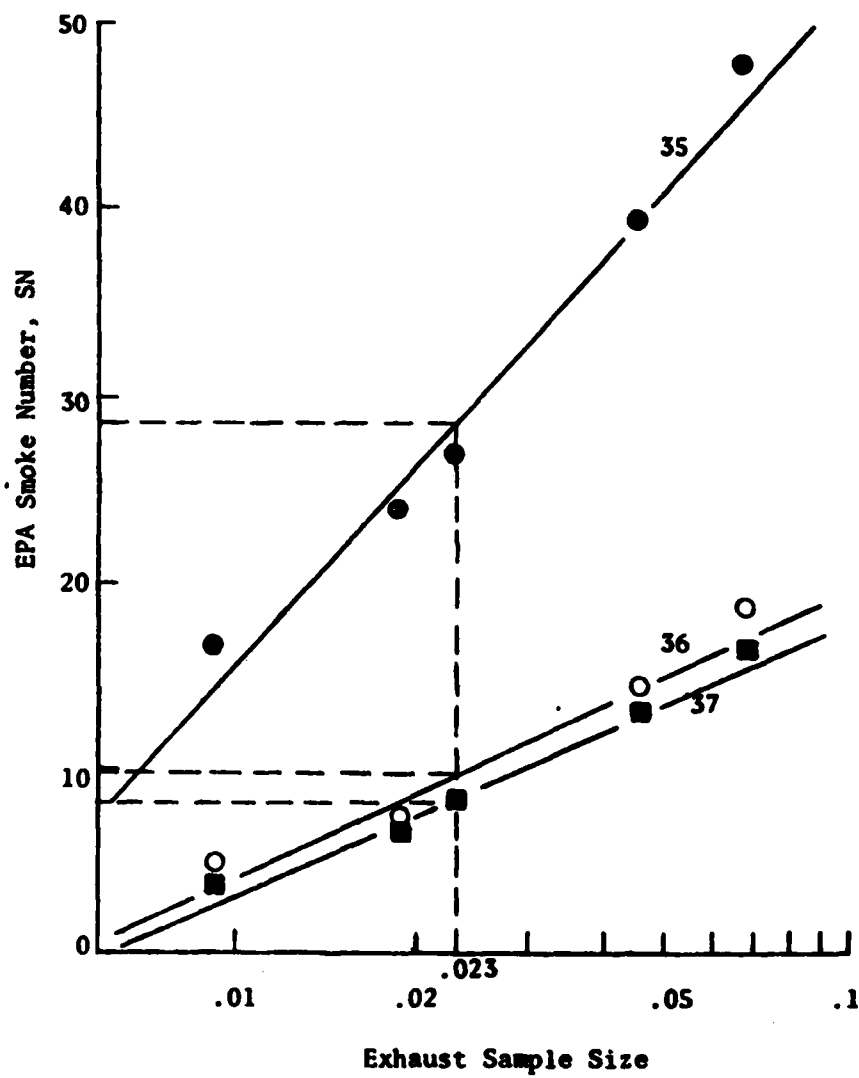


Figure 71 - Smoke Number Evaluations for Experiments 35, 36, and 37

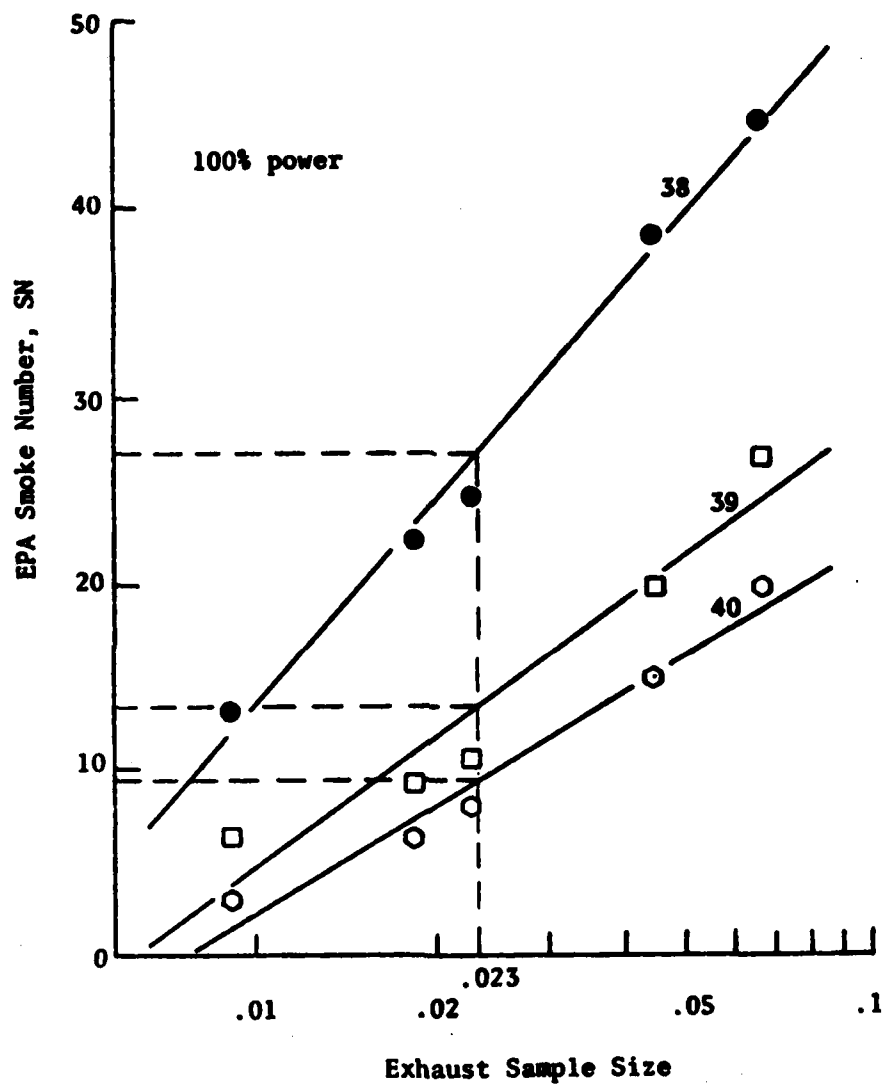


Figure 72 - Smoke Number Evaluations for Experiments 38, 39, and 40

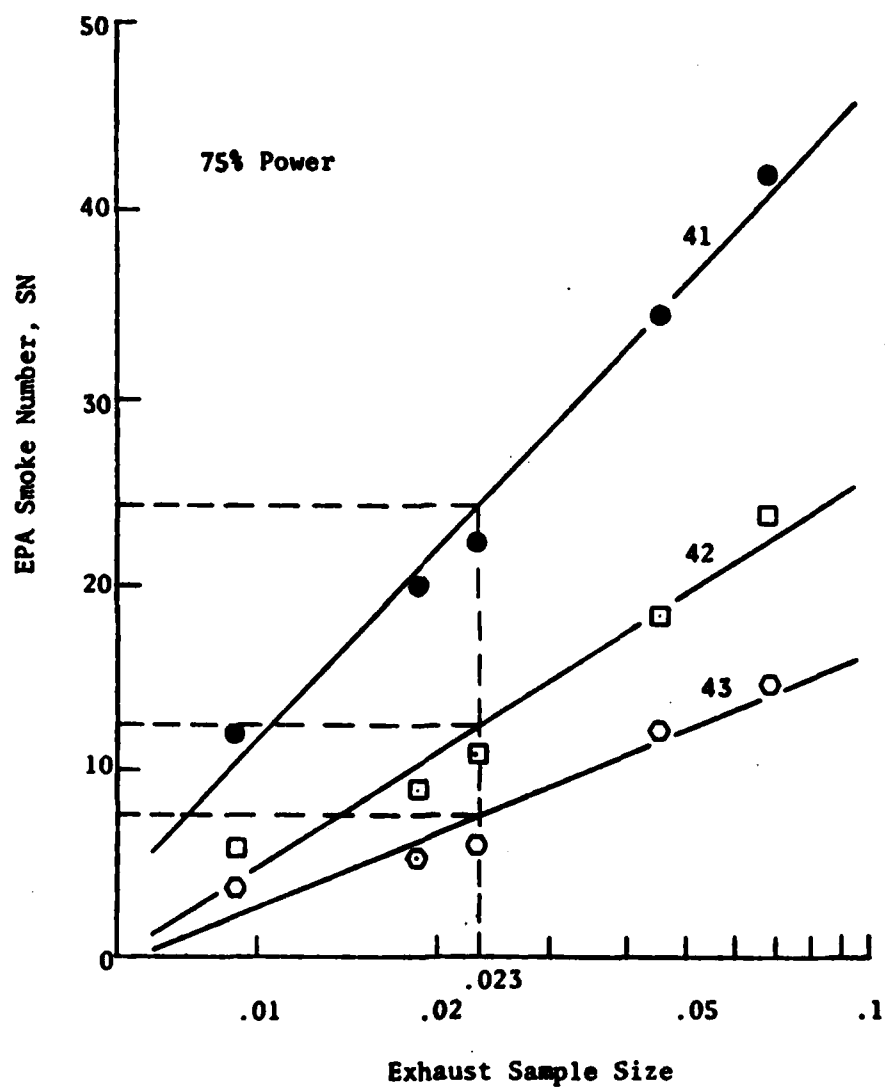


Figure 73 - Smoke Number Evaluations for Experiments 41, 42, and 43

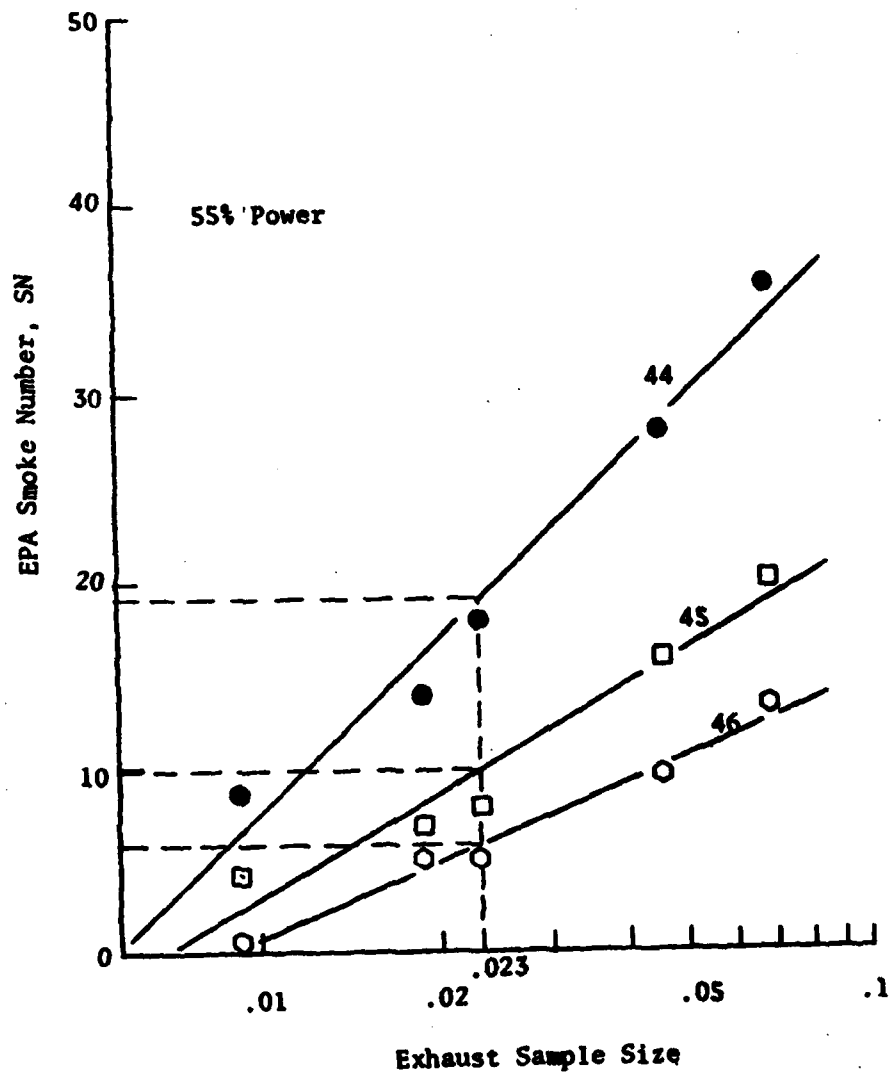


Figure 74 - Smoke Number Evaluations for Experiments 44, 45, and 46

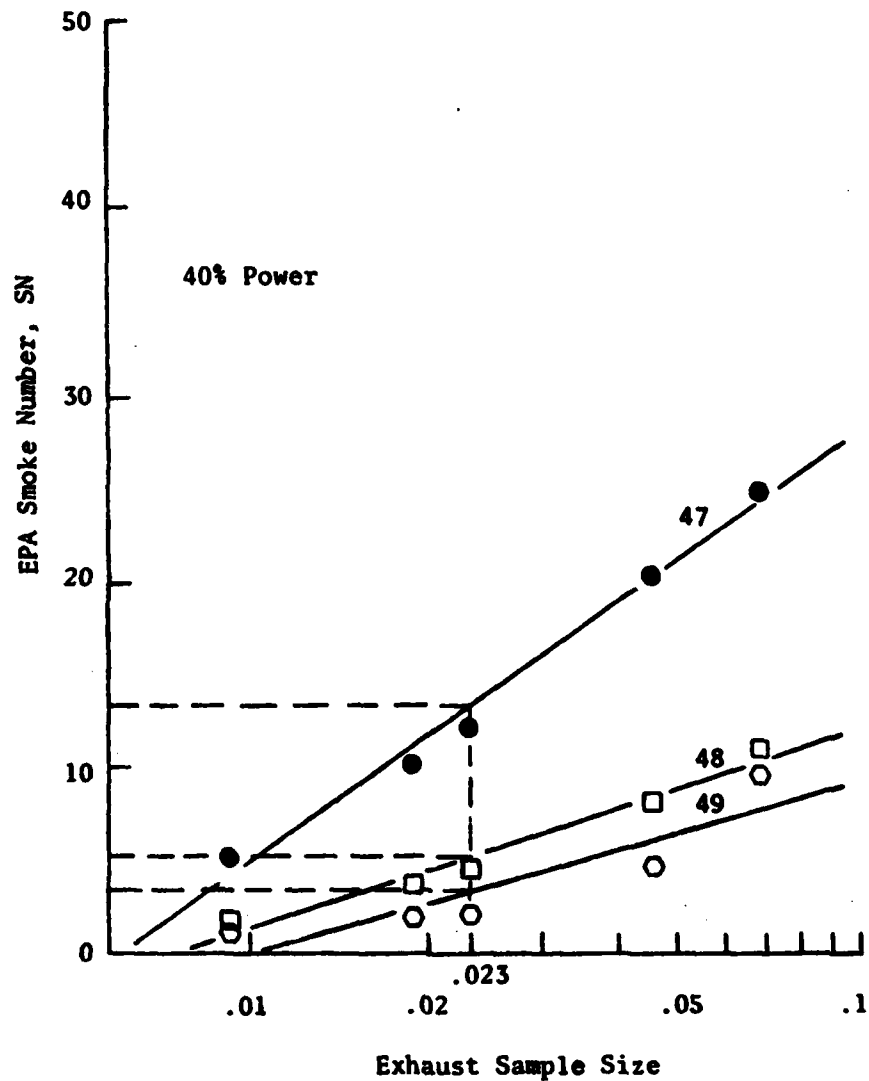


Figure 75 - Smoke Number Evaluations for Experiments 47, 48, and 49

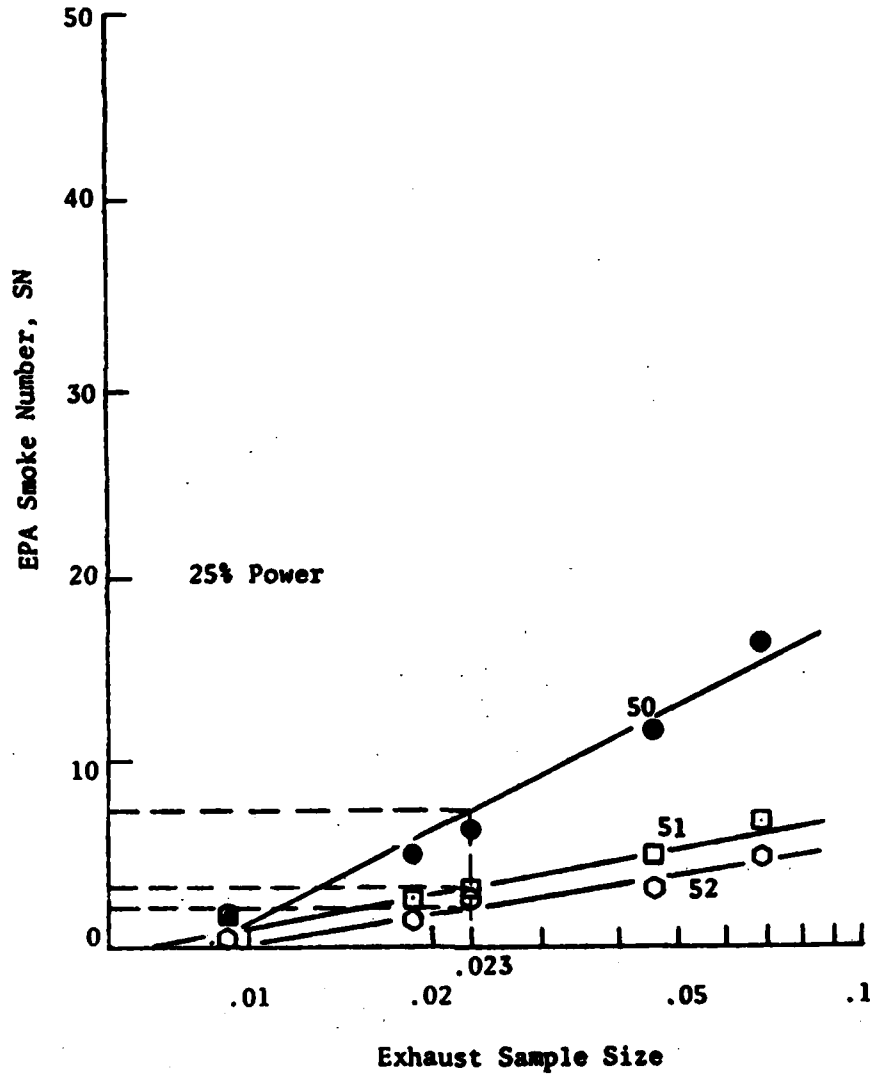


Figure 76 - Smoke Number Evaluations for Experiments 50, 51, and 52

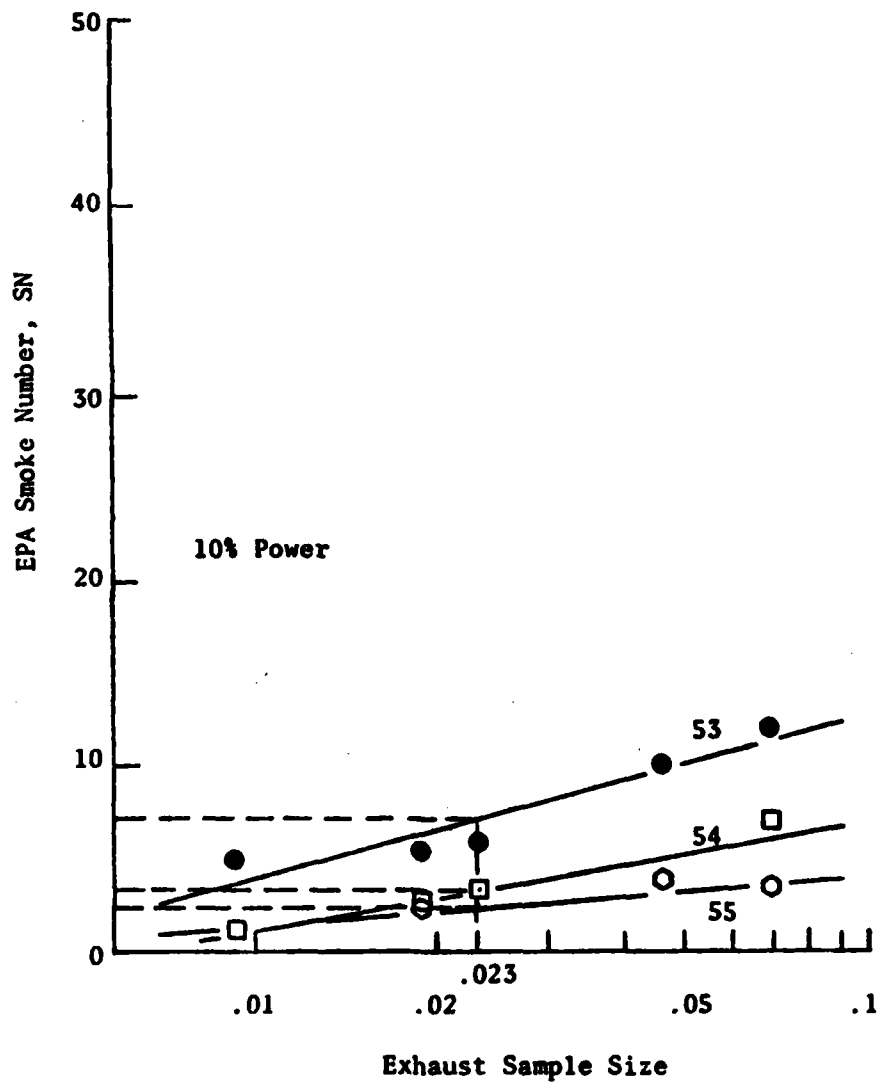


Figure 77 - Smoke Number Evaluations for Experiments 53, 54, and 55

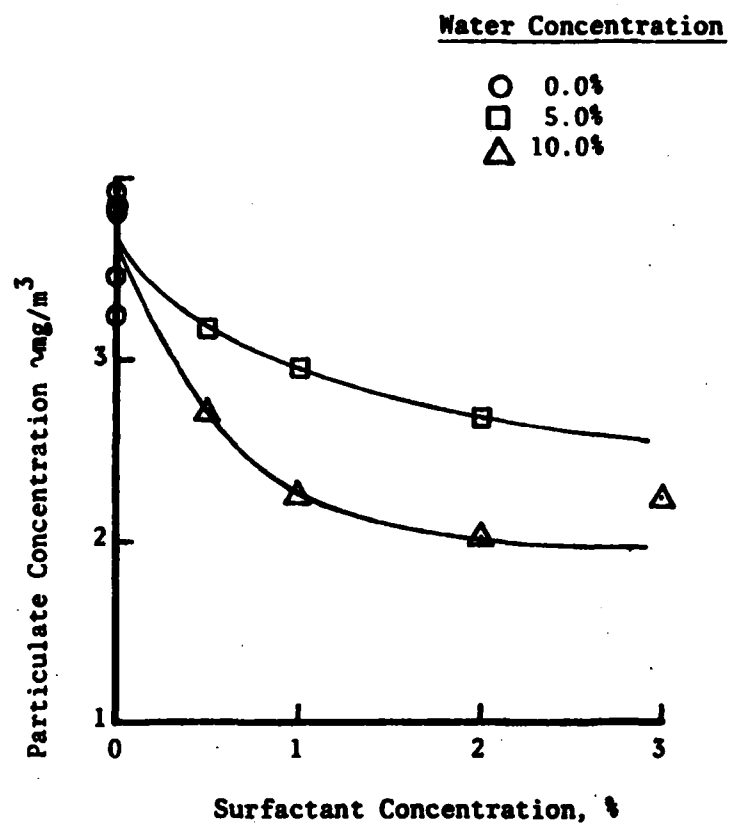


Figure 78 - Summary of Effects of Emulsion Characteristics on the Reduction of Exhaust Particulates, Program Phases 1-3

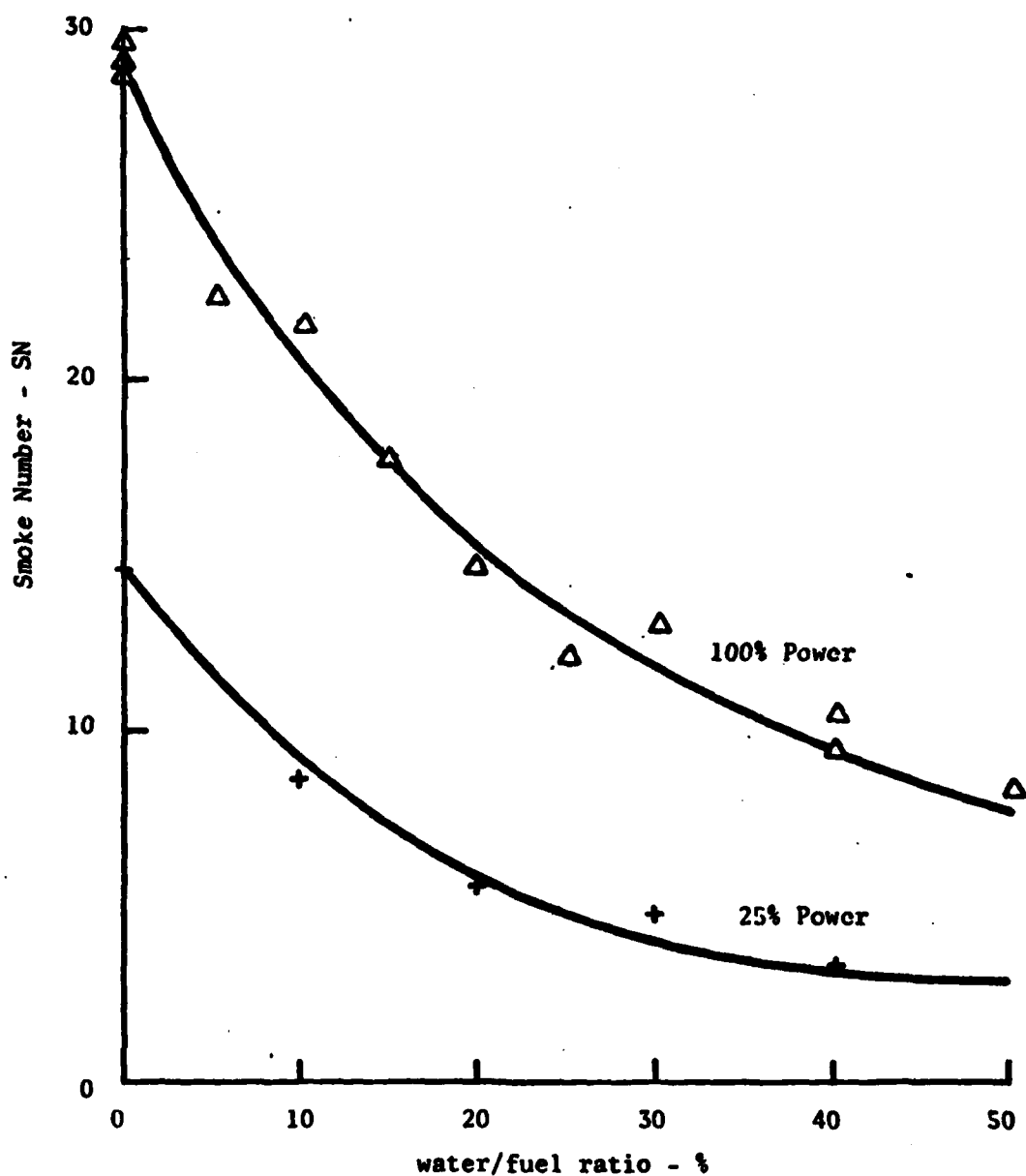


Figure 79 - Summary of Effects of Water Concentration on the Reduction of Smoke Number, Program Phases 4-7

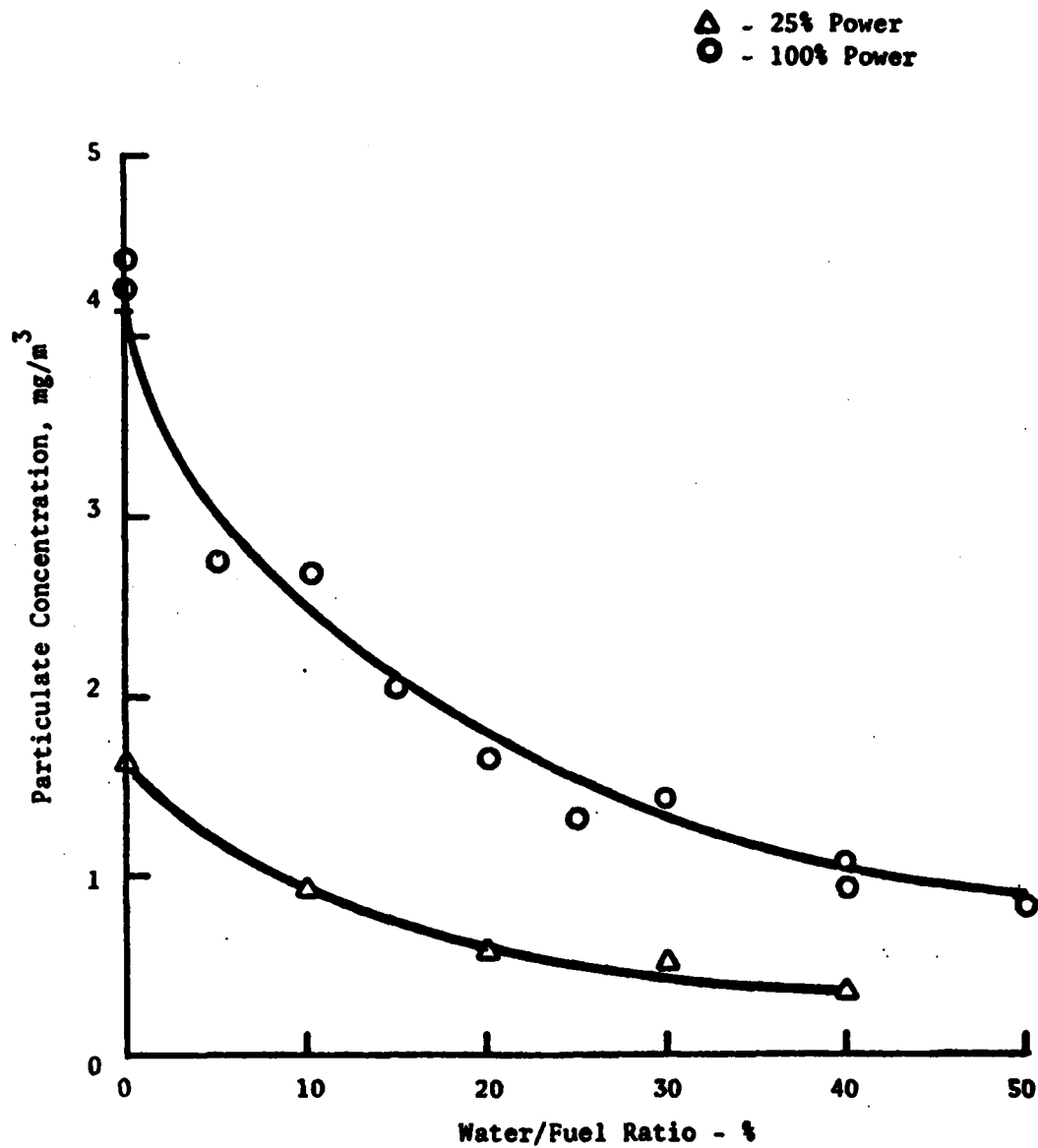


Figure 80 - Summary of Effects of Water Concentration on Particulate Concentration

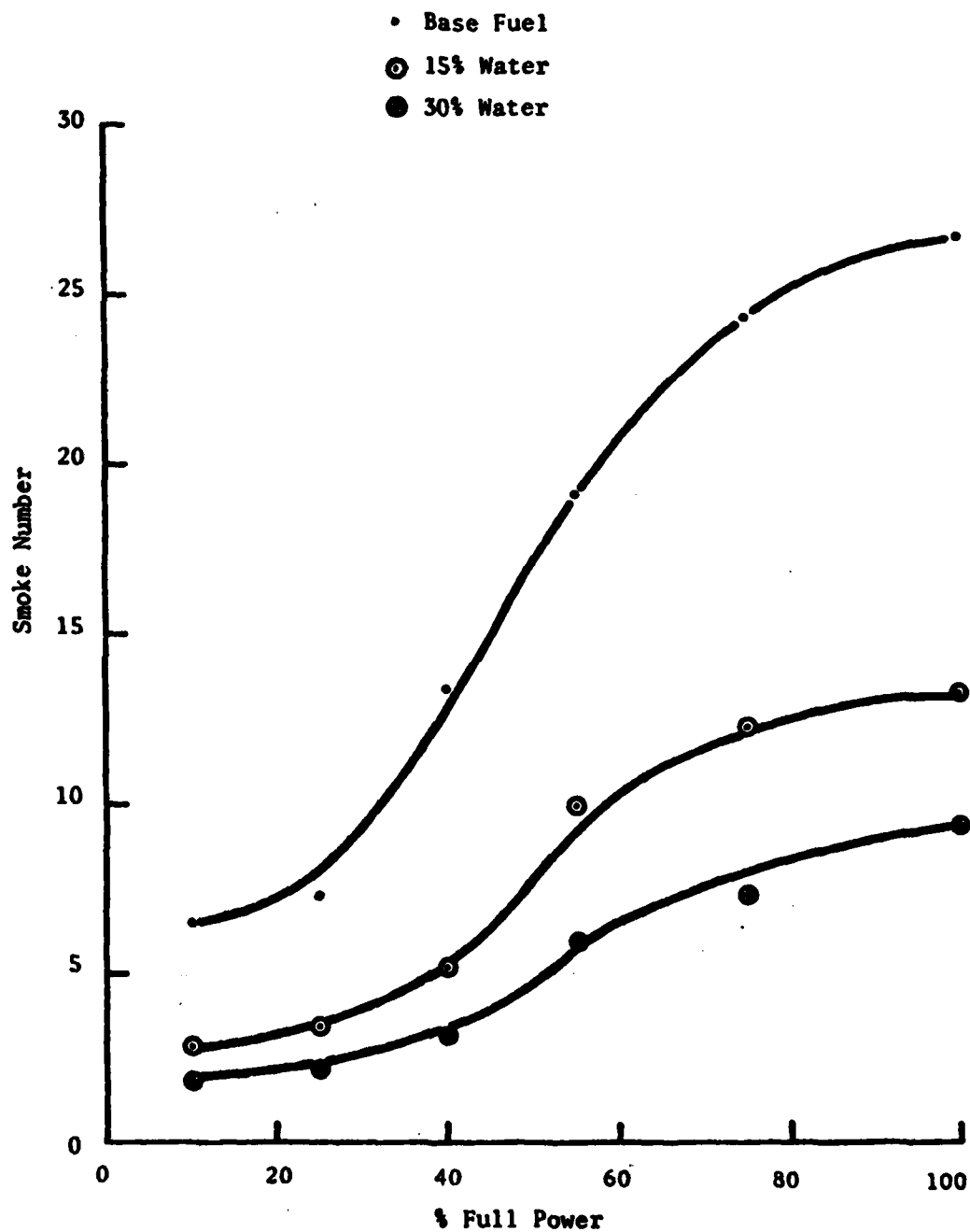


Figure 81 - Summary of Effects of Fuel/Water Emulsions on Smoke Number Throughout Engine Power Spectrum

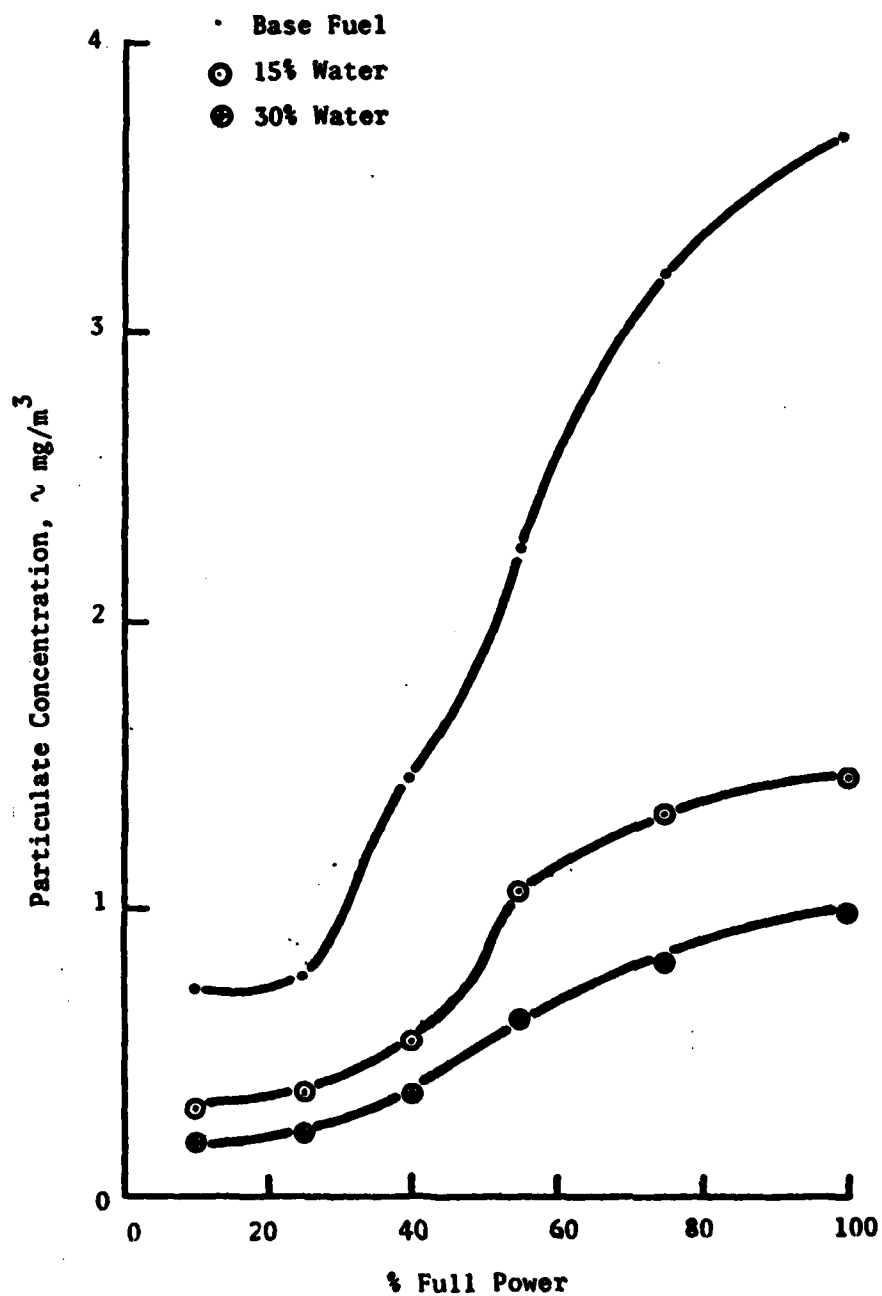


Figure 82 - Summary of Effects of Emulsion Characteristics on Particulate Concentration Over Engine Power Spectrum

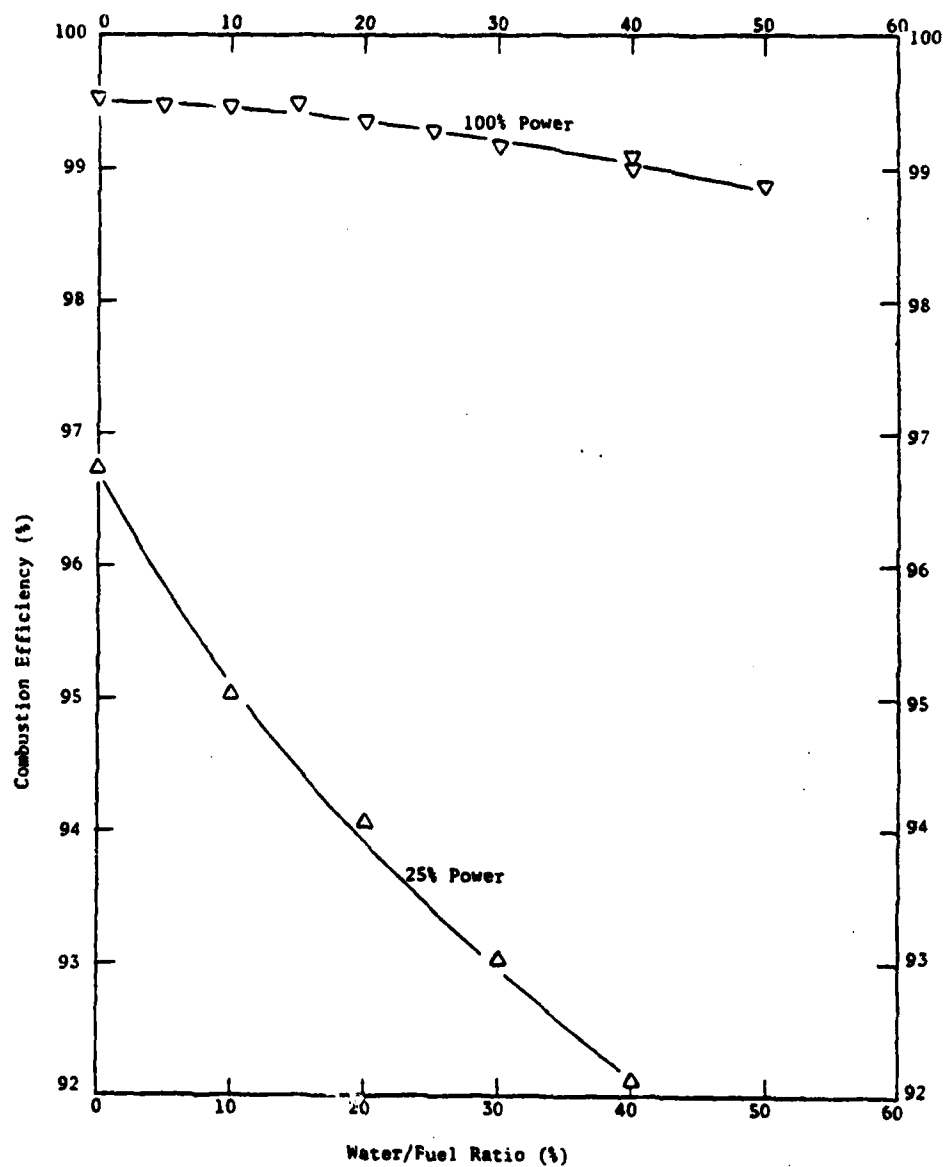


Figure 83 - Effect of Water Concentration on Combustion Efficiency

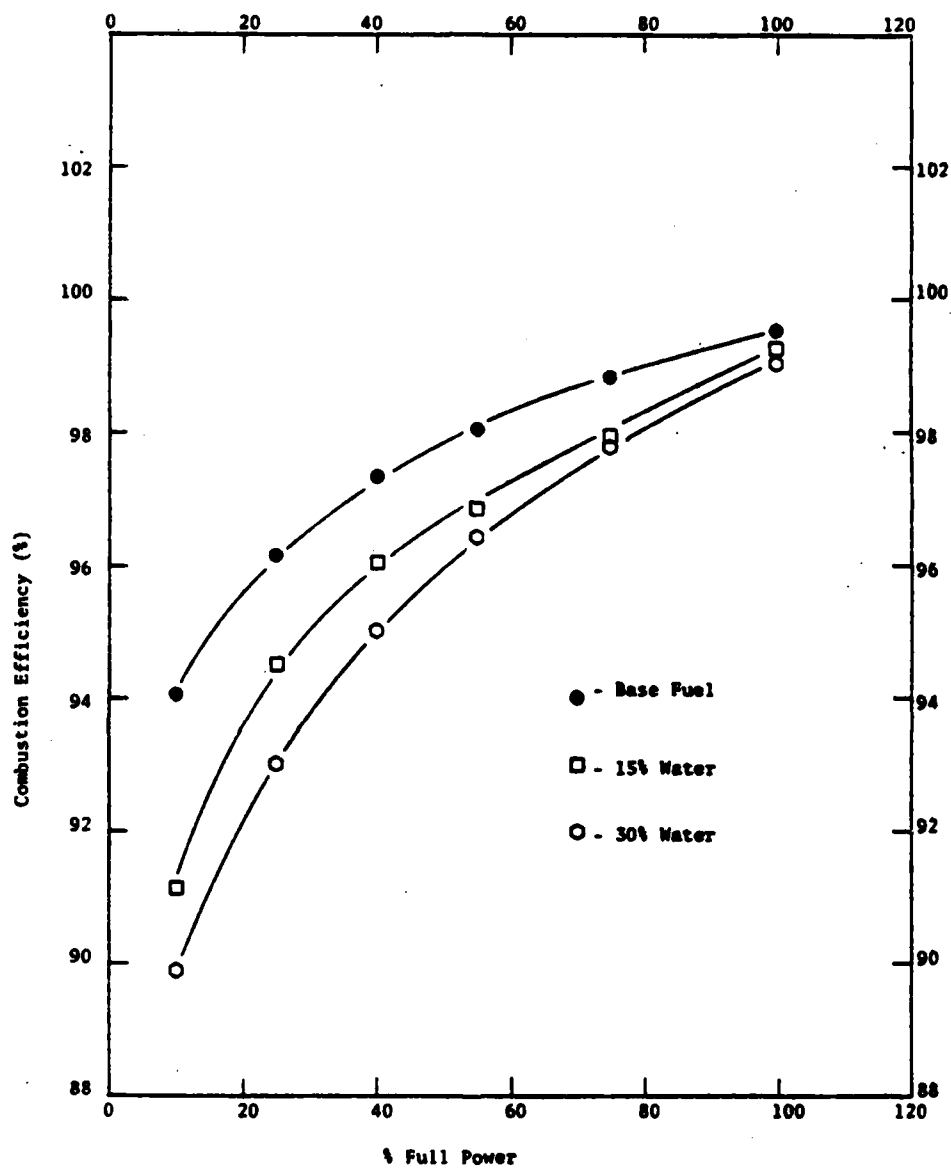


Figure 84 - Effect of Water Concentration on Combustion Efficiency Over the Engine Power Spectrum

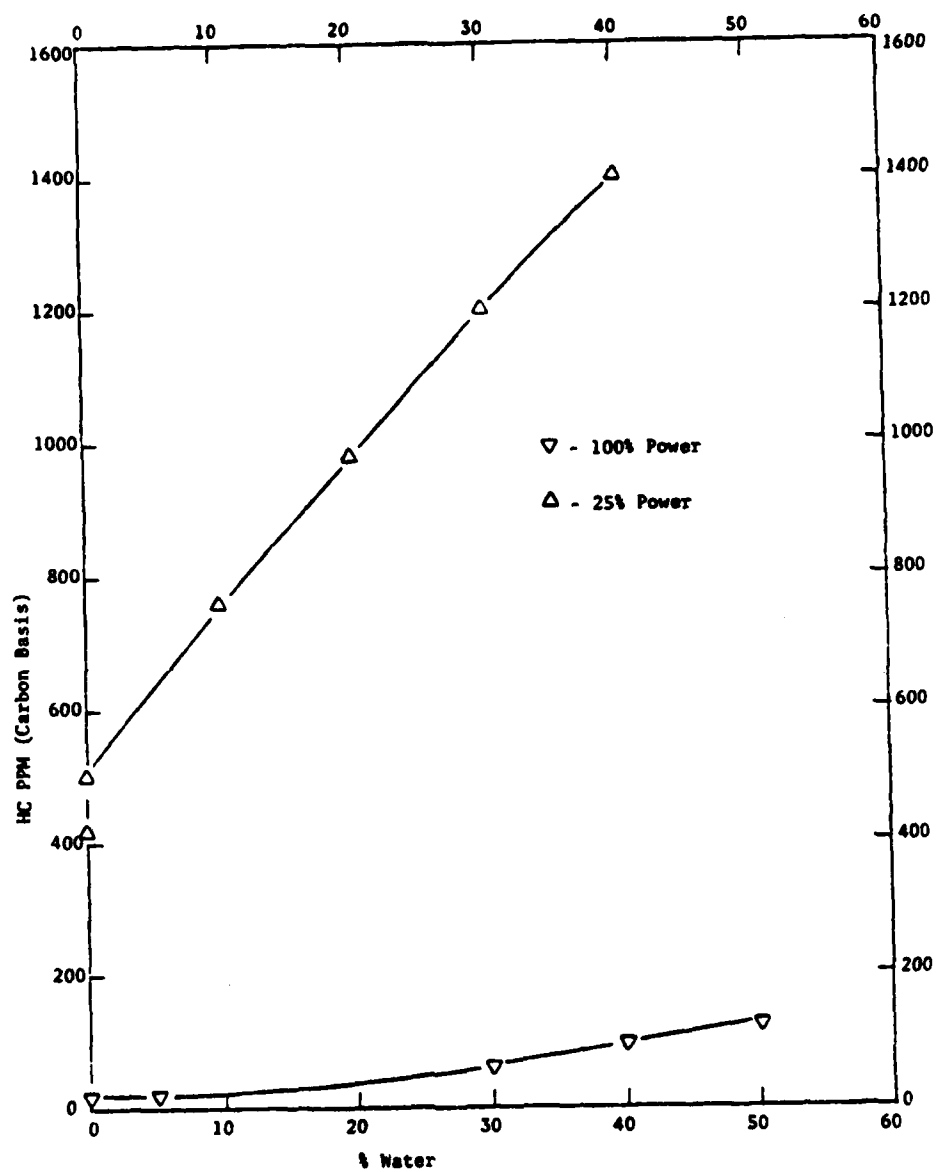


Figure 85 - Effect of Water Concentration on Hydrocarbon Emissions

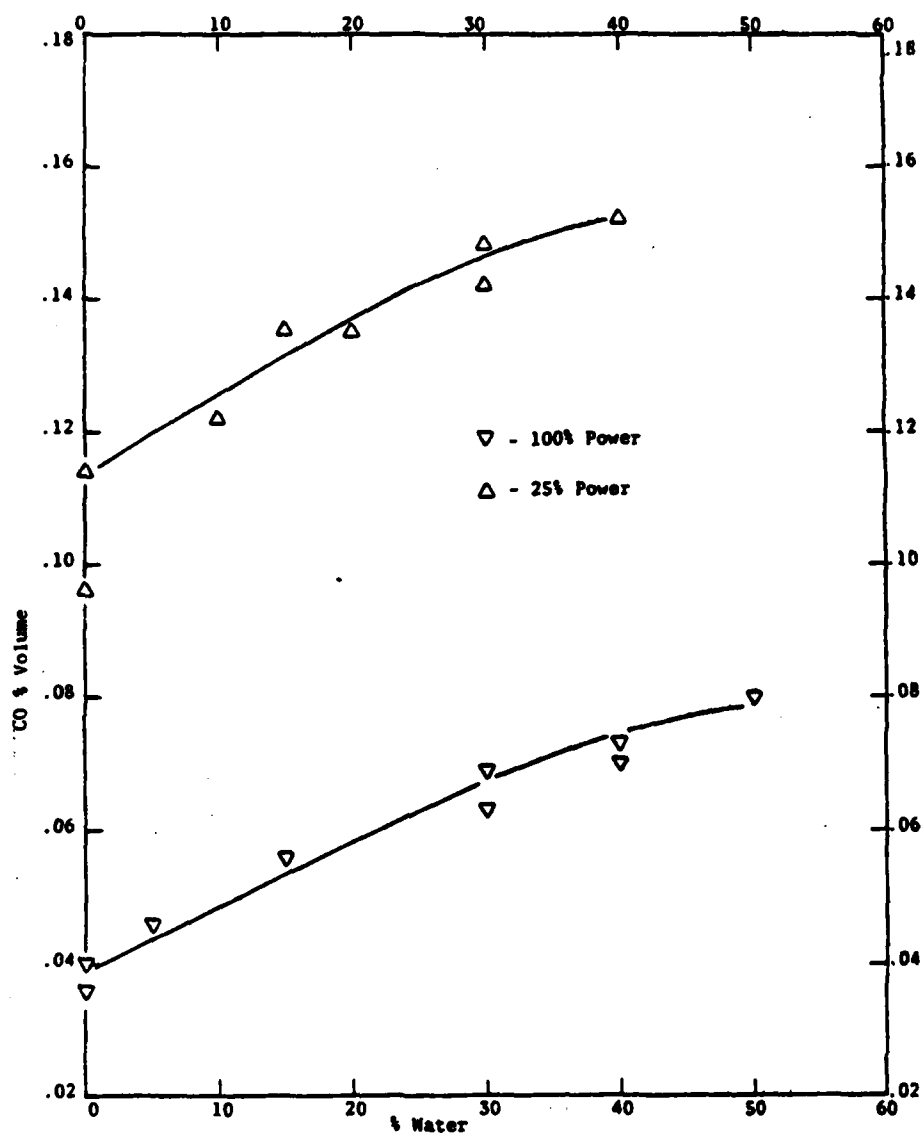


Figure 86 - Effect of Water Concentration on Carbon Monoxide Emissions

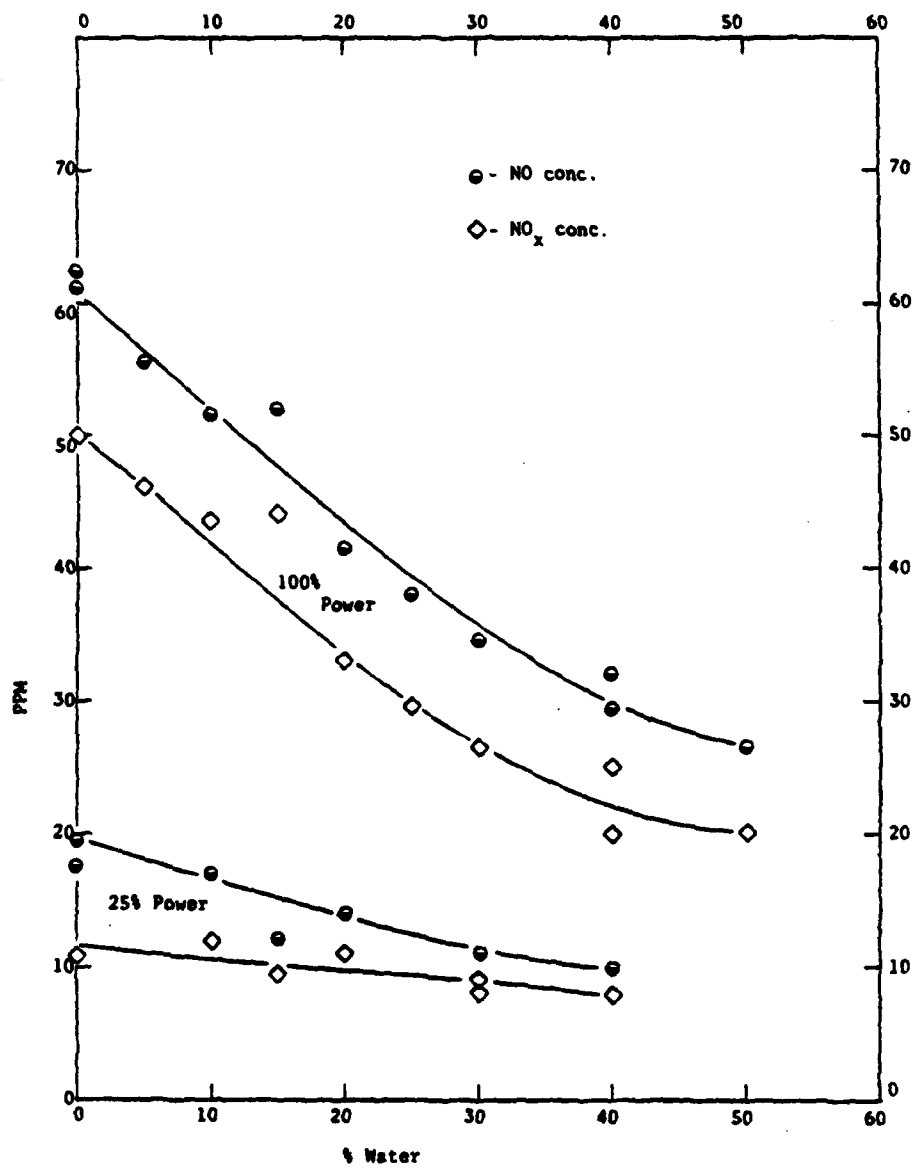


Figure 87 - Effect of Water Concentration on Oxides of Nitrogen Emissions

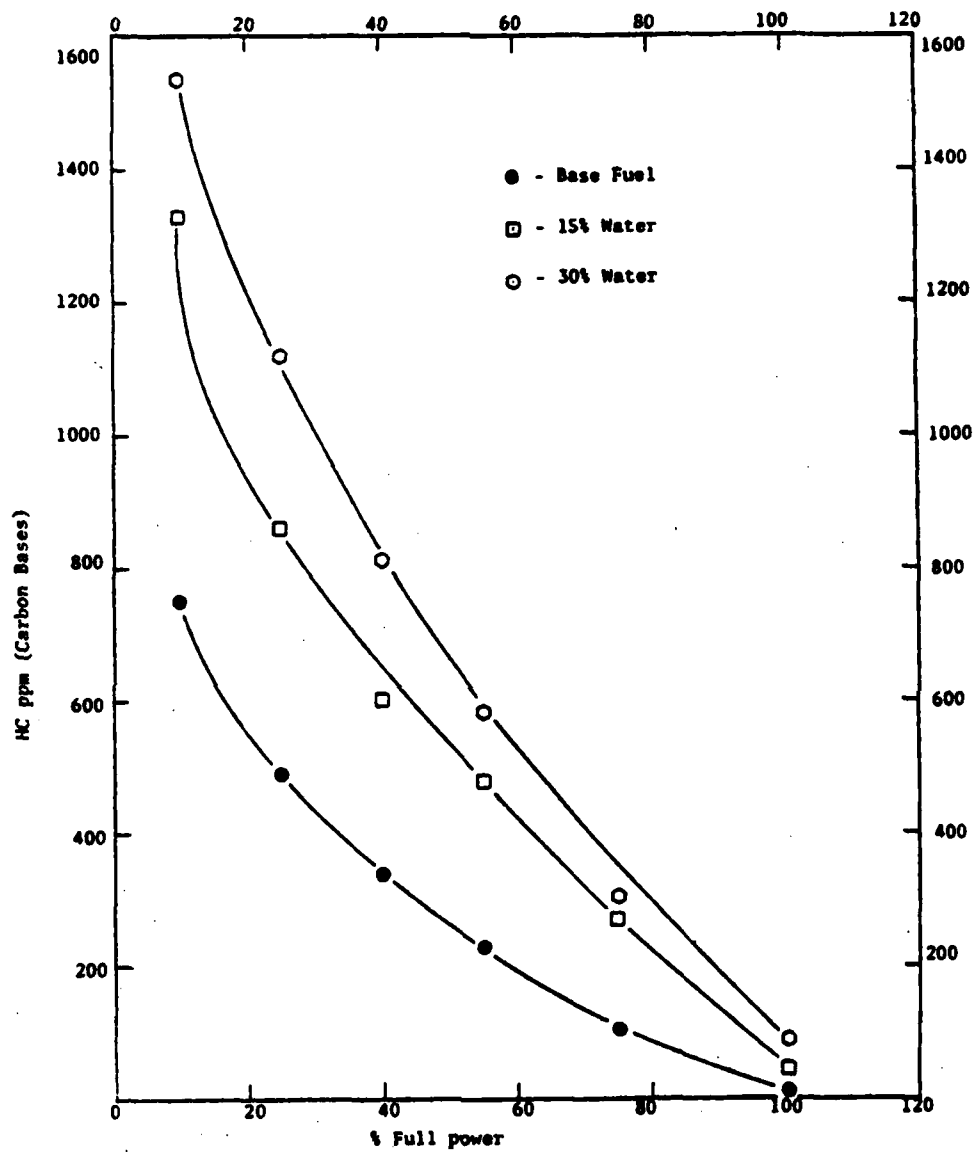


Figure 88 - Effect of Water Concentration on Hydrocarbon Emissions for Engine Power Spectrum

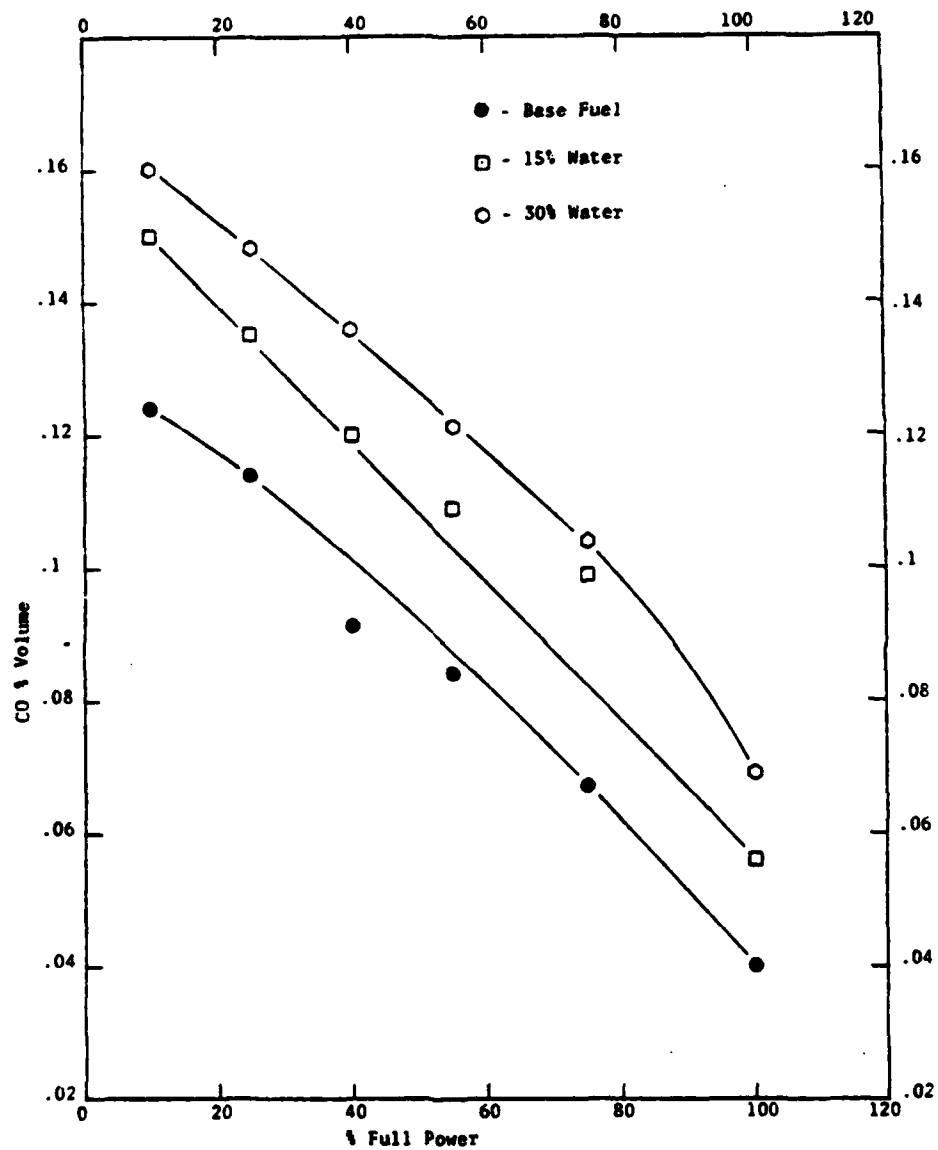


Figure 89 - Effect of Water Concentration on Carbon Monoxide Emissions for Engine Power Spectrum

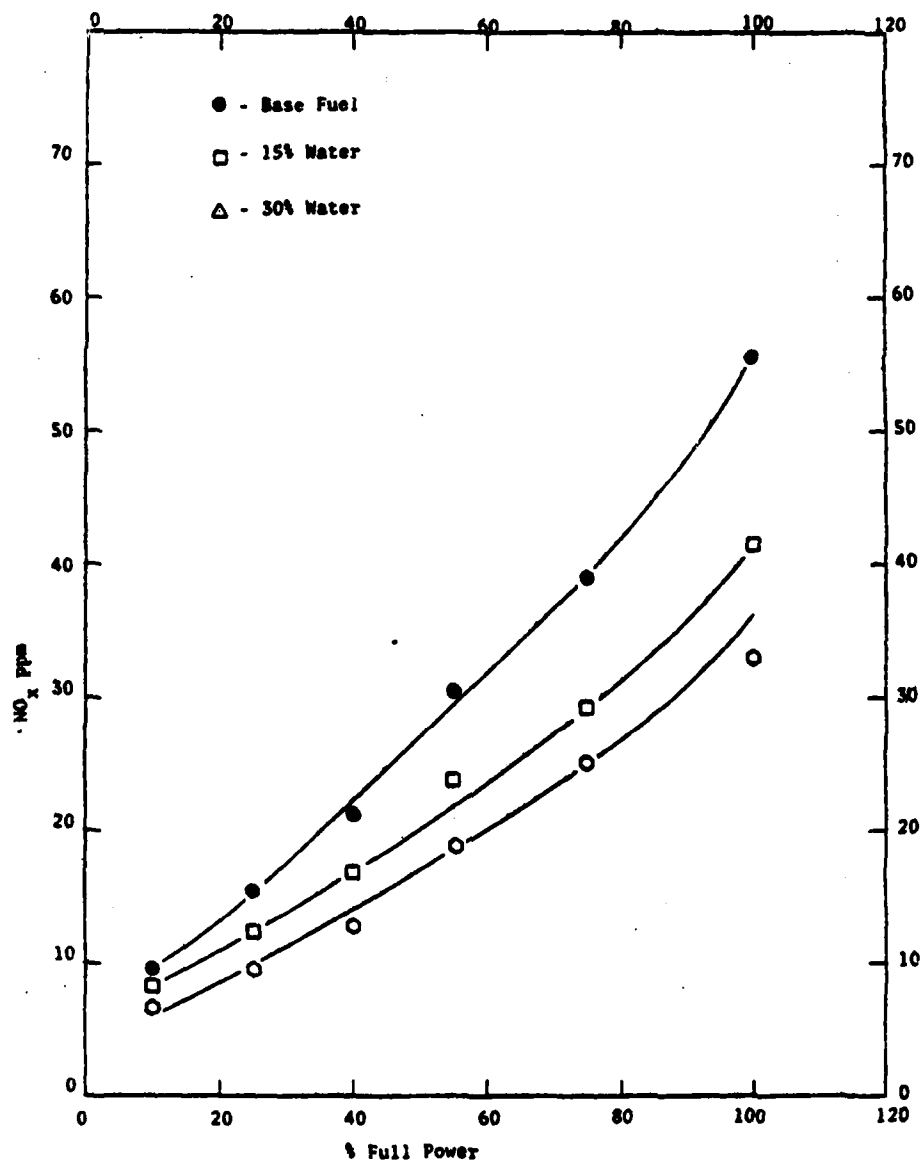
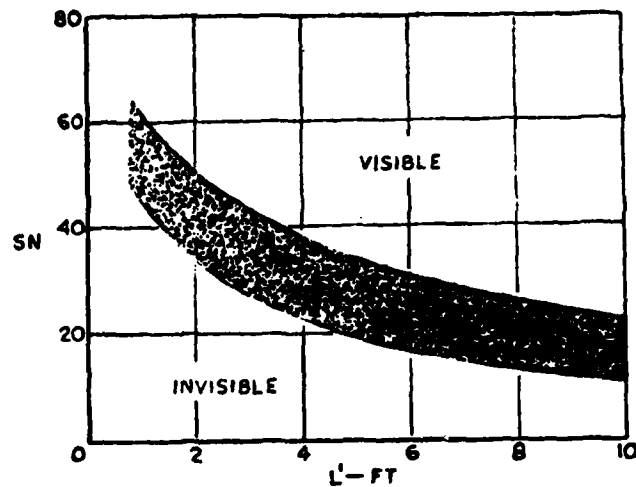
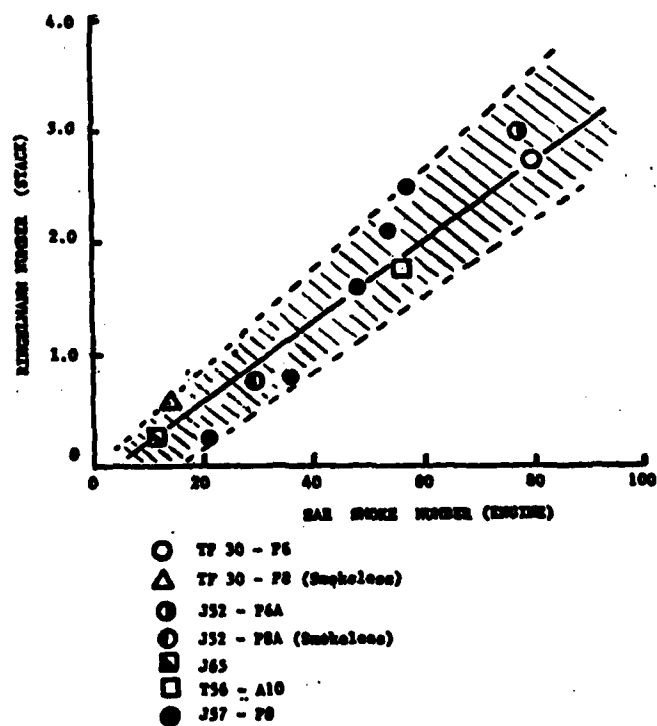


Figure 90 - Effect of Water Concentration on Oxides of Nitrogen Emissions for Engine Power Spectrum



(a)



(b)

Figure 91 - Correlations of Smoke Number to Plume Visibility According to (a) Champagne (1971), (b) Kelly (1973)



